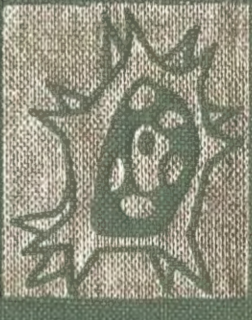
A Secondary BOOK of BIOLOGY

3. *Ecology and Applied Biology*

K W ROGERS





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3. Ecology and Applied Biology

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Consultant's Foreword

In preparing this book we have been able to select from illustrations that have appeared in the magazine *Understanding Science*. These provide lucid, attractive visual communication which we think appropriate at this level. In addition there are many new illustrations. Where possible subjects are introduced by, or concluded by, practical and theoretical problem-solving material which provides opportunities for teachers to develop in their pupils an investigatory approach to the subject.

We have attempted to stimulate readers by the challenge of curiosity. Almost all the problem-solving material has been used with classes within the C.S.E. band of the ability spectrum, and their favourable reaction was the main criterion for its inclusion.

C.S.E. Biology is seen by the majority of the Regional Boards not merely as the acquisition of knowledge, but as an opportunity for the use of practical and cognitive skills. The expectation is that assessment procedures which attempt to measure these abilities will have a beneficial 'backwash' effect; they will ensure that teachers whose concern is the development of these skills will be encouraged rather than inhibited by the way in which their product is measured.

One hopes that at least a start has been made on a generation of text books which incorporate this aim.

J. F. Eggleston.

The first volume in this series of biology books, 1. Common Core, covered the basic biology requirements of the various C.S.E. syllabuses. This, the third volume, deals with an *optional* part of the syllabus together with its companion volumes, 2. Genetics and Evolution and 4. Bacteriology and Hygiene.

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Contents

1. The Interdependence of Organisms

The Interdependence of Organisms

INDIVIDUAL living organisms cannot exist in isolation.

Almost all that is known about animals and plants shows that they are as dependent on one another as they are on the non-living matter around them such as air and water.

Requirements of animals and plants

If you try to make up a list of the things needed by a typical flowering plant in order to live, you will probably arrive at something like this:

1. Light for photosynthesis.
2. Carbon dioxide for photosynthesis.
3. Oxygen for respiration.
4. Mineral salts for the production of substances such as proteins.
5. Water.
6. Space in which to grow.
7. Insects for pollination (in some cases).
8. Animals for seed dispersal (again in some cases).
9. Something in which to anchor itself.

Similarly we can look at the requirements of animals, and such a list might read:

1. A source of food to supply energy and raw materials which must be of the right type for the particular animal. Each sort of animal has its own very specific food requirements which are governed by behaviour and feeding and the digestive mechanisms which it possesses.
2. Oxygen for respiration.
3. Water.
4. Building materials (nest, tubes).
5. A means of getting rid of its excretory products.
6. Space.
7. A means of staying in favourable surroundings.

From these lists we can tell quite a lot about where such animals and plants could, or could not, exist, and also something of their dependence on one another.

Carbon dioxide is not made in sufficient quantities by a green plant in respiration for it to be able to support itself in photosynthesis. Therefore animal and non-green plant respiration is essential for continued active photosynthesis. Where is oxygen to be obtained from for respiration in both plants and animals if not from photosynthesis carried out by green plants?

The mineral salts which are needed by plants are made available to them by the action of bacteria, and by the excretion of animals.

Pollination by insects will not take place if those particular insects are not present.

Nest-building materials, as well as sites for nest building, are often supplied by plants, and if you look again at the two lists you will be able to find other ways in which animals and plants depend on one another, and perhaps on others of their kind.

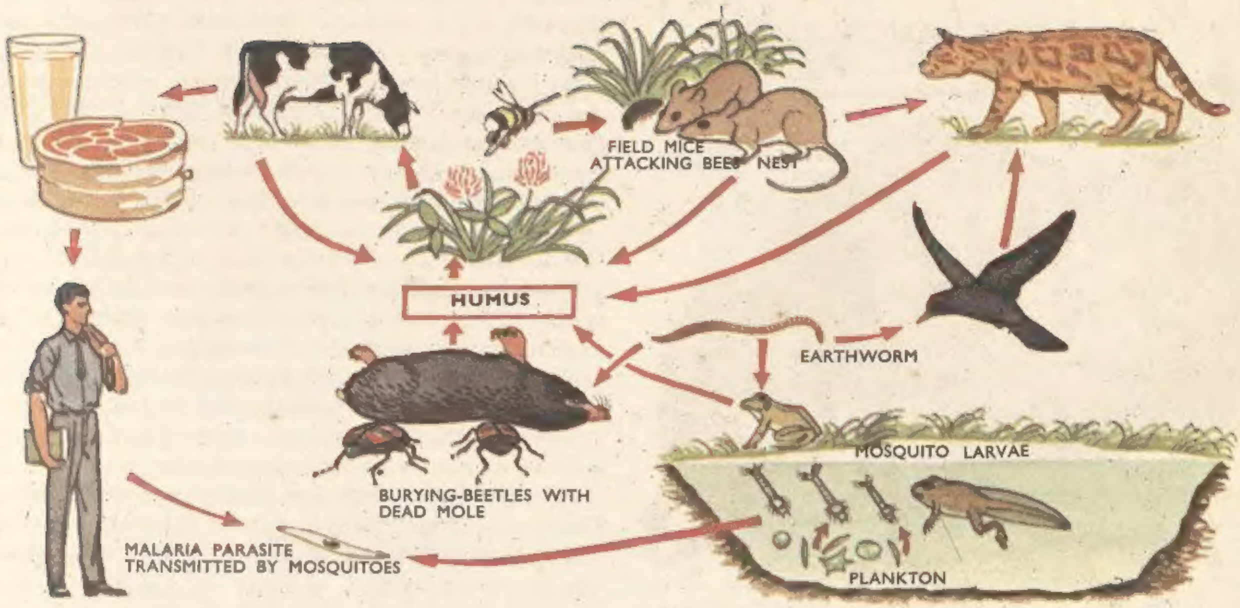
Food chains

One of the basic differences between animals and plants which you will find in the lists is that the latter can normally manufacture complicated organic food materials from water, carbon dioxide and mineral salts. Animals must obtain ready-made organic foods which they can build up into their own bodies. Obviously they must depend upon plants for the initial supplies of food materials. The relationship may be a simple one such as a cow eating grass and depending directly upon the plant for food. A slightly more complicated relationship is that of an antelope eating grass and in turn being preyed upon by lions. These relationships are known as *food chains* and they may be made up of many links. All have one thing in common: they start with a plant as the *primary producer* of food. The first animals to occur in the chain are usually found in large numbers, but successive links are represented by smaller numbers of animals until the major predator in a chain may be represented by a single individual in any given territory. An example of this is found in a field of clover where there will be large numbers of bumble-bees and their underground nests. Field-mice, present in small numbers, feed on the young bees in the nest and are in turn hunted by hawks. There will probably be only one hawk or family of hawks in the immediate area. The distribution of the hawks depends upon the available food. An area containing five hundred mice obviously cannot support many hawks, as the food supply of the latter would soon be exhausted.

Similar chains are found in the sea. The small planktonic plants – the primary producers – are eaten by planktonic animals which form the food of the shoaling fishes such as herrings. The shoals contain large numbers of fish and are preyed upon by larger fish such as the cod which is not so common and does not swim in shoals.

Man can be placed at the head of a great number of chains because he uses a wide variety of natural products for food. Man is, of course, far more common than many of the animals he uses for food, but this is a specialised case and the general rule of decreasing numbers still holds good in other cases.

Parasites must be included in food chains to give a complete picture. The final stage in this case consists



A few of the inter-relationships between plants and animals of land and fresh water.

of very large numbers of small animals feeding on a large one. A fish may have hundreds of parasitic round-worms (*nematodes*) inside it. A man ill with malaria has many thousands of protozoan parasites in his blood. Where a parasite has more than one host, cross-links are produced between food chains.

The food chains must not be thought of, however, as simple, straighforward relationships involving only a few animals. All the individual food chains found in a particular environment are linked to each other in some way so that the structure of the animal and plant population of an area remains stable. To take the clover field example again, mice are also preyed upon by owls and by cats. Cats occur at the head of a chain leading from dead clover plants via worms and birds, and thus link two chains starting with a clover plant. In theory one can say that the number of cats influences the yield of clover seed via the activities of mice and bees, but so many factors are acting in nature that the effect would probably be balanced out. It is true, however, that severe reduction in the numbers of a common animal will change a lot of things in the environment. Myxomatosis, which killed large numbers of rabbits in Britain a few years ago, deprived the foxes of much of their natural food. They began to catch birds more frequently, as many poultry-keepers discovered. The lack of rabbit grazing also meant that open hillsides began to sprout bushes. The study of the food chains and the relationships between the animals of a particular environment is called ECOLOGY.

In the sea the chains are linked together in much the same way. Individual steps may be bypassed by some animals. For example, the large whalebone whales feed directly upon the minute planktonic organisms. The dying planktonic organisms sink to the sea-bed where they are eaten by molluscs, annelid worms and other organisms. These in turn are eaten by starfish, cuttlefish and bottom-living fishes such as cod and plaice. Large squids eat all types of animals on the sea-bed and themselves form the main diet of the elephant seals and the large, toothed whales such as the sperm-whale. Dead animals, including the large carnivores which have no predators but which die from disease or old age, are consumed to some extent by scavenging animals such as burying beetles, vultures and hyaenas. A proportion of the organic material, however, will be broken down by bacteria and provide the simple compounds which plants will again build up into organic food materials. Similarly, in the sea, dead animals are decomposed and the dissolved salts are returned by currents to the surface layers where they are used by the planktonic plants.

Symbiosis

Perhaps in some ways the simplest and most direct example of animal and plant interdependence is provided by some cases of SYMBIOSIS. This is the name given to the living together of two organisms to the advantage of both.

Perhaps the best known example of symbiosis is that between hermit crab and a sea-anemone (e.g. *Adamsia*).

Hermit crab and anemone, symbiotic partners.

The anemone is often found attached to the shell in which the hermit crab lives. In their long history hermit crabs have developed the habit of sheltering within the empty shells of molluscs such as periwinkles and whelks. The hind portion of the body has lost its hard covering and would otherwise be unprotected. As the crab gets bigger it outgrows its shelter and so has to find a new one. Often, a sea-anemone attaches itself to the crab's shelter and it may envelop part of the crab's own shell as well. The growth of the crab and anemone keep pace with one another and the crab may have no need to change its shell – more and more of it is sheltered by the anemone. As the crab moves about in search of food the anemone is brought into contact with a greater supply of food, and the crab no doubt gains a certain amount of defence from the anemone's stinging cells.

Hydra, a hollow-bodied animal, contains microscopic plants, called algae, in its endoderm cells.

The algae receive light through the transparent body wall of Hydra, carbon dioxide from the animal's respiration, nitrogen from protein breakdown in the animal, and protection.

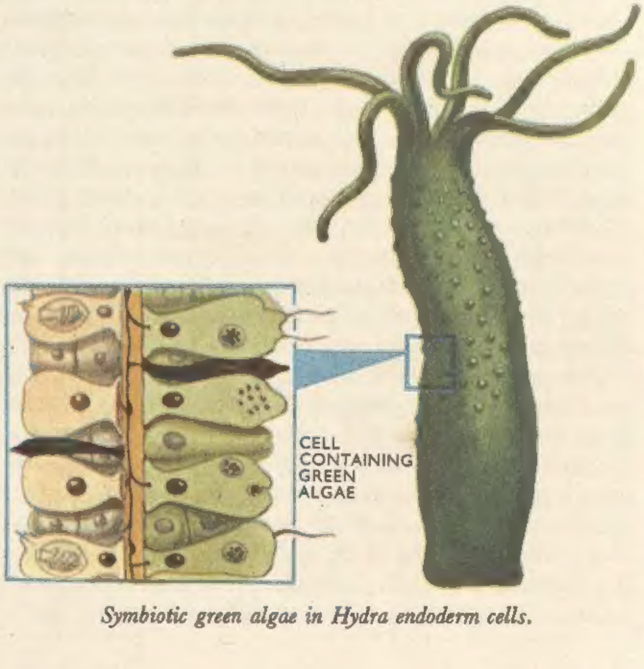
Hydra receives some oxygen from the algae photosynthesis and has some of its excretory products removed (carbon dioxide and nitrogen). In this case it is probable that the algae get the best of the relationship.

Animals much bigger than Hydra manage well enough without algae in their cells; however, we can see that this interesting association could easily work to the advantage of both organisms.

Many protozoans and single-celled algae live symbiotically with animals. Symbiotic plant cells are particularly common in planktonic-shelled protozoans – the foraminiferans and radiolarians – and in corals and other many-celled animals in tropical seas. It is possible that such associations have arisen because of the relative lack of minerals in the surface waters of warmer seas. Radiolarians have a frothy layer of protoplasm outside the main mass of protoplasm. Within the froth are embedded a number of tiny yellow plants. These obtain shelter and have a ready supply of food in the form of the waste materials that the radiolarians produce. The oxygen that the plant cells release in their food-making processes is available to the radiolarians and possibly food substances as well. By using up the waste materials alone the plants render a useful service to the animals.

A most interesting association is that between *Carteria* – a simple plant – and the flatworm *Convoluta.* The adult Convoluta obtains a 'stock' of Carteria which, being green, is able to photosynthesise. Carteria gains from Convoluta a supply of carbon dioxide and nitrogenous waste material for the formation of carbohydrates and proteins. In exchange Convoluta obtains some oxygen, a by-product of photosynthesis, and is also able to absorb some of the carbohydrates etc. manufactured and exuded by Carteria. If long periods are spent in the dark and Carteria is unable to photosynthesise then it is digested by Convoluta as food.

Symbiotic micro-organisms – bacteria, fungi (yeasts) and protozoans – play an important role in the lives of

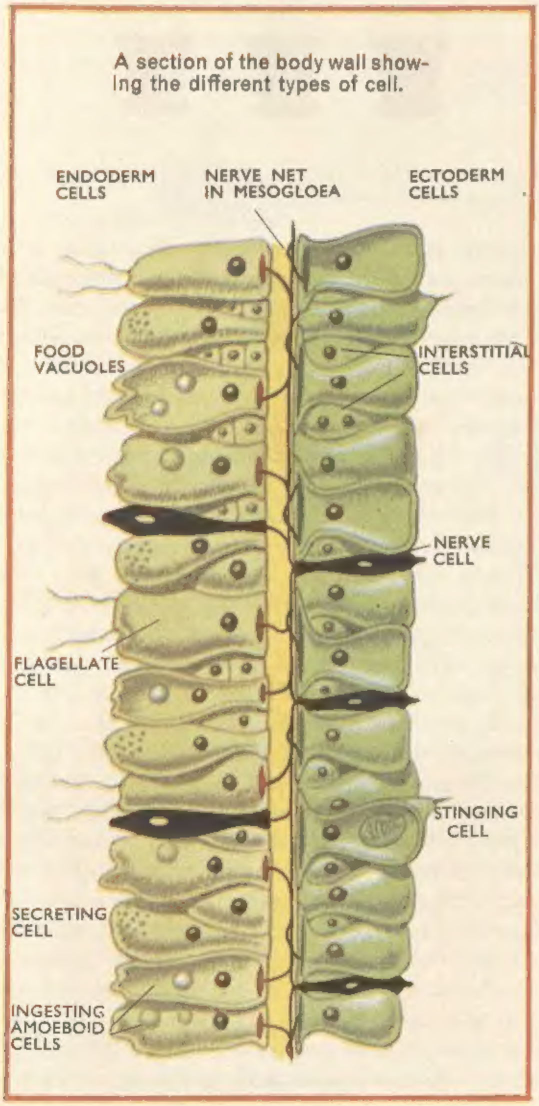


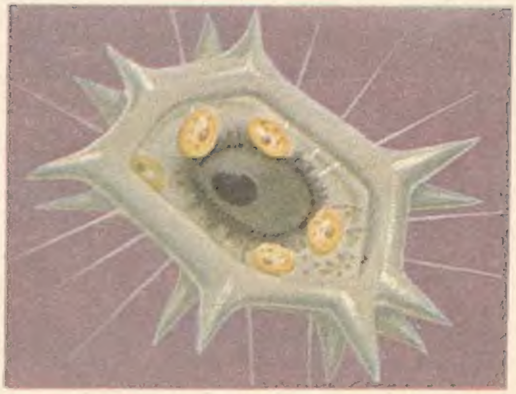
Symbiotic green algae in Hydra endoderm cells.

many insects. They may be harboured in the gut or in the special cells (*mycetocytes*) which are often grouped together to form organs called *mycetomes*.

Most termites have symbiotic protozoans in the hind part of the gut. These actively ingest the wood particles that the termite has eaten and break them down, releasing substances that the termites can absorb. Experiments show that the termites depend on the protozoans for much of their food, and when the latter have been removed, so that the termite has none in its gut, it loses weight rapidly and dies.

One wood-eating termite grows only when the wood on which it feeds harbours a fungus population. Some wood-eating cockroaches have protozoans and bacteria in their gut and certain scarab beetle larvae house bacteria that digest cellulose.



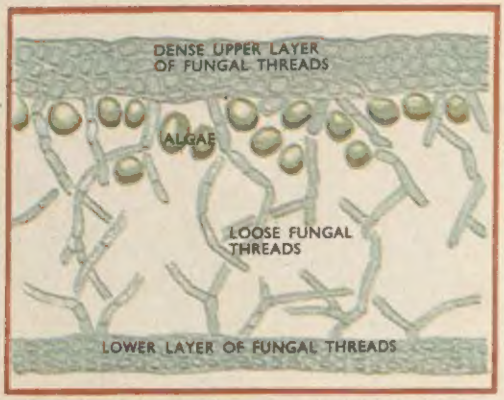


A radiolarian containing symbiotic yellow cells.

Mammals harbour vast populations of bacteria in their stomachs and intestines. Ruminants such as cows and sheep have special chambers in the stomach in which the bacteria live, feeding on cellulose in the grass on which their hosts feed. By their activities the bacteria produce simple organic acids (e.g. acetic acid) from the cellulose, which the cows and sheep can absorb through their gut wall. Bacteria also produce vitamins (e.g. B_{12}) in the gut. This may be the only supply of some of these essential food substances. In rabbits and horses the symbiotic bacteria are harboured in chambers or *caeca* of the large intestine.

There are several well-known associations between birds and game animals. Cattle egrets, for example, are often seen in the company of buffalo and elephants.

Cattle egrets and oxpeckers accompany the larger game animals. The former feed on the insects stirred up by the animals' hooves and may warn them of approaching danger. Oxpeckers rid their hosts of parasites and obtain food in the process.



Section of a lichen shows the algae among the fungal threads. In some species the algae are more scattered.

They flourish on the insects kicked up by the feet of these animals. The egrets appear to be aware of approaching danger rather more quickly than the game animals and it is likely that their actions in this respect serve to warn their larger companions.

A frequently observed phenomenon in Africa is that of oxpeckers running over the backs of hippopotami and rhinoceroses. These birds rid their partners of injurious and annoying insects and in doing so obtain a ready supply of food.

In the plant world there are many examples of symbiosis: root-nodule bacteria infect the roots of legumes (e.g. Clover); some orchids and heathers form close associations with fungi (called *mycorrhizas*), as do forest trees such as the Beech and Pine.

Lichens are peculiar plants formed by the union of a fungus and an alga. They play an important part in the formation of soils, being the first to colonise rocks. The substances that they produce dissolve the rocks away, forming the fine particles that are washed down by rain to form soils. They consist of algal cells embedded in a weft of fungus threads. The algae that occur within lichens are very similar to free-living forms but the fungi are unable to lead an independent existence. The alga is protected and supplied with moisture while the fungus absorbs the food materials made photosynthetically by the alga.

Nature's dustmen and the nitrogen cycle

Every organism, no matter how it depends on others, must have an adequate supply of nitrogen-containing compounds in its diet. This is because nitrogen is an essential constituent of proteins of which all living matter is composed.

All animals rely ultimately on plants for their food, hence for their intake of nitrogen. It is important that plants have enough nitrogen in their diets, and so there must be a constant supply of its compounds in the soil. As soon as these nitrogen compounds are removed more must be put back to take their place for the plant and animal life not to suffer. The series of events by which nitrogen-containing substances are returned to the soil and to other animals is called the *nitrogen cycle*.

The nitrogen cycle is operated by what might be called Nature's cleaning department. It employs a large number of workers to dispose of dead bodies and excrement. The efficiency of this 'department' is shown by the fact that one seldom sees dead animals or even skeletons in the countryside.

The biggest tomato plant is the one which has been fertilized with the most nitrogen-containing sludge.

Bacteria and other micro-organisms play a very important part in the nitrogen cycle and are responsible for the final breakdown of organic compounds. However, their action is less spectacular than that of various carrion feeders that quickly dispose of dead bodies. Without these carrion feeders the land would be littered with animal bodies in various stages of decay.

Among birds the best-known of the carrion feeders are the vultures, including the largest living flying bird – the Andean Condor. One group of these birds is distributed over America, and another ranges from the Mediterranean and Africa to India and China. Vultures typically soar high in the sky and can pick out a source of food from very high up. Their sight is quite amazing. Observers have noted that a dead animal quickly attracts several vultures. The soaring birds can probably see each other as well as any food, and one swooping bird will attract the attention of others.

A few vultures will rapidly reduce a goat carcass to a mass of skin and bone – ripping the flesh away with their hooked beaks. Their claws are usually weak in comparison to those of other birds of prey which attack living animals. There is even one vulture – the Lammergeyer of the Himalayas and the Middle East – that exists largely on bones and bone marrow. It carries bones up to some height and drops them until they break up.

The scavengers among mammals are the jackals and hyaenas. Jackals are small wolf-like animals that

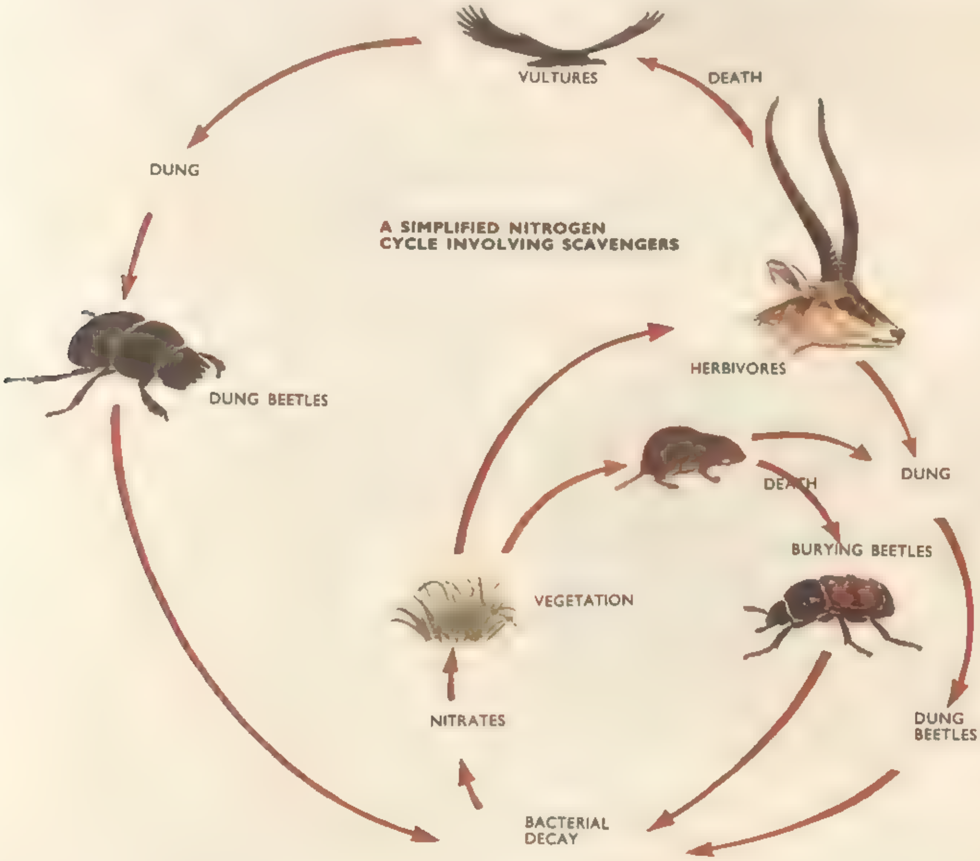
sometimes hunt in packs. They occasionally kill other animals but more often feed on the remains of the lion's kill. Hyaenas are cowardly animals and will usually attack only small animals such as rats. They feed mostly on carcases and have powerful bone-crushing teeth and jaws. Hyaenas usually go around in groups hunting for carrion.

All that is left after such scavengers is usually a few pieces of skin and bone. These are then attacked by various beetles that find nourishment in such materials. More interesting among the insect scavengers, however, are the various burying beetles and dung-feeders.

Small corpses such as mice and voles rapidly attract the attentions of various sexton beetles. These black, or orange and black, insects have been known to bury a mouse in light soil in a few minutes. The beetles usually work in pairs and bury the corpses by shovelling the soil away from underneath. The head is often broad and aids the legs in the shovelling work. When buried, the corpse serves as food for the beetles and their larvae. The beetles lay their eggs in the body and the young are already provided with food. Under the soil, the corpse keeps moist and bacterial action can continue more rapidly than it would do at the surface.

In summer all our meat and fish must be covered to protect it from flies. In the wild, however, these flies do a service by laying their eggs in carcases. The larvae contribute to the breaking down of the material and its eventual return to the soil.

Almost before the dung of cattle and other animals has cooled it is visited by flies and beetles. They feed there and lay their eggs. The grubs rapidly absorb the putrefying material, leaving only a collection of dried plant remains – valuable food for some beetles.



Beetles of the scarab family are well-known buriers of animal dung. The once-sacred scarab of Egypt collects dung and rolls it into a ball and then rolls the ball to some suitable place for burial. Some scarabs feed on the dung themselves, while others may use it to lay eggs in. The Dor-Beetle, a relative of the scarab, tunnels underneath cow-dung and fills the ends of the tunnels with dung before laying its eggs there.

The value of these scavengers and the myriads of insects and other organisms that break down plant and animal remains is enormous. The fact that bacteria and other micro-organisms can reduce refuse to harmless,

A scarab beetle rolling a ball of dung with its hind legs. An egg laid in the dung develops into a grub that feeds inside the ball (shown cut open). The finished ball is considerably bigger than the beetle itself.

Burying beetles attending to the corpse of a mouse. Several kinds of beetle engage in this work. In sandy soil, the corpse is rapidly buried.

The skull of the Striped Hyaena showing the heavy jaws and the powerful bone-crushing teeth.

even useful, material has only recently been used by Man in composting plants. This is an attempt by Man to avoid wastage and to return material to the soil as is done by Nature's own dustmen.

The final breakdown of refuse to useful material is done by two main sorts of bacteria, NITROSOMONAS and NITROBACTER. Their action can be investigated by the experiment shown on the facing page.

During this process some nitrogen is lost to the atmosphere. How can this be returned to the soil for recirculation?

About four-fifths of the air is nitrogen. This represents an enormous supply of the element. If we could breathe in nitrogen and convert it into protein, the problem would be very simple. But this does not happen, for the nitrogen breathed in is breathed out again unchanged. This supply of nitrogen is not available to plants either (except for a few bacteria and algae). A plant growing in soil that contains no nitrogen will eventually wither and die even though its leaves are surrounded by the nitrogen of the air. Pure nitrogen, the element itself, is remarkably unreactive. Plants need certain *compounds* of nitrogen, i.e. nitrogen chemically combined with other elements. There are, however, certain bacteria that can utilise this atmospheric nitrogen. Because they can take nitrogen from the air and build it up into nitrates they are called *nitrogen-fixing bacteria.* Some live in swellings called nodules on the roots of a family of plants called legumes. Some of the better-known legumes are peas, beans, vetch and clover. This is an example of *symbiosis.* The plant and the bacteria live together for mutual benefit. The bacteria have somewhere to live and the plant can use some of the nitrates manufactured by the bacteria. Any excess nitrate goes to enrich the soil. The planting of a field of clover and the end-of-season ploughing it back into the soil are often used by farmers to enrich the soil. The nitrate in the soil also becomes enriched by thunderstorms when the intense heat of the lightning causes some nitrogen to combine with oxygen. This dissolves in the rain, forming a very dilute solution of nitric acid which supplies the plant with nitrate. A very small amount of ammonia is formed.

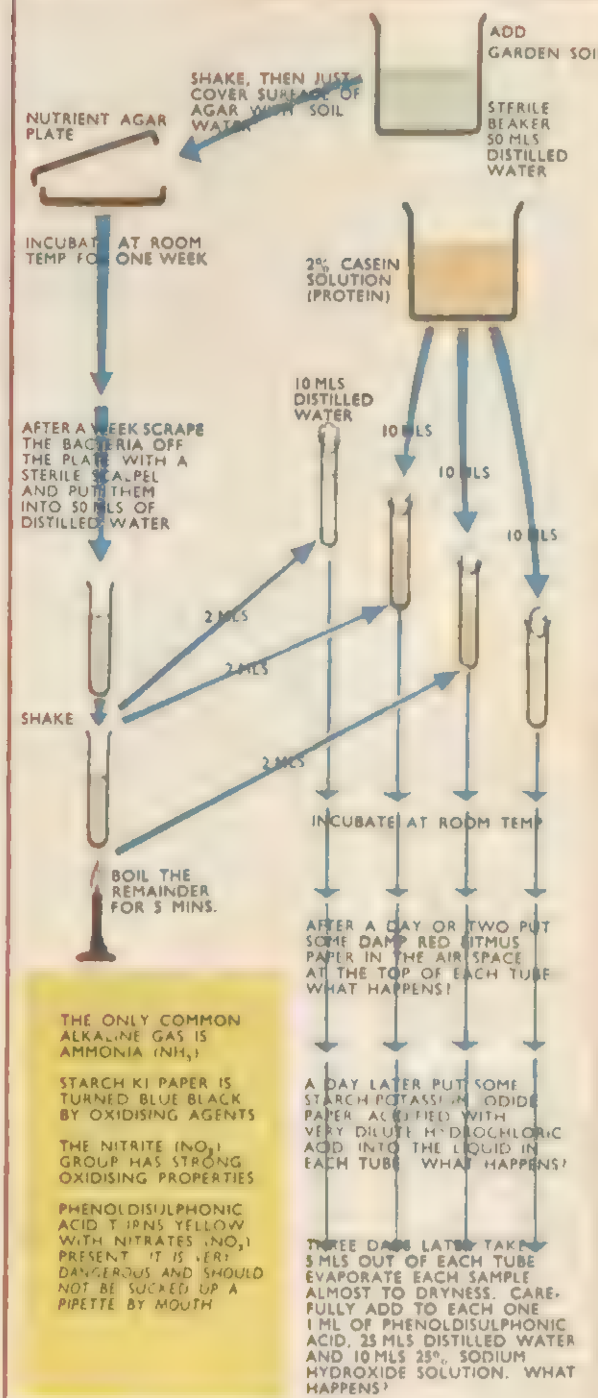
Nitrates are compounds which can easily be taken in and used by plants. Because they are so soluble in water they are also easily washed away. Enormous quantities of nitrates are washed away to the sea and lost from the soil every year. The sea, incidentally, is the world's largest store of nitrates. Leaching of nitrates from the soil cannot be helped, but loss of sewage to the sea can be helped and constitutes an enormous waste of nitrogen. This is the direct result of city dwelling rather than living in farming communities where the sewage was automatically returned to the

Root nodule bacteria live symbiotically in tiny nodules on the roots of legumes. They fix atmospheric nitrogen, building up organic nitrogen-containing molecules, which the legume can obtain from them through its vascular tissues. The bacteria obtain sugars in return.

soil as a fertilizer. Once in the soil, different bacteria would set to work on it breaking down the complicated protein molecules into ammonium compounds and then more bacteria would convert these to nitrates which the plants could use. In doing so the bacteria would get energy for themselves. There are, incidentally, other bacteria which are harmful to agriculture. These live in poor waterlogged soil and get their energy and oxygen by robbing the ground of nitrates and setting nitrogen free into the air.

We have already said that the sea is a source of nitrates. There are also nitrogen-fixing bacteria living in the surface waters of the sea. They form part of the floating and drifting life known as plankton and convert atmospheric nitrogen to protein, which provides fish food. Fish can in turn be eaten by man and other animals, and so once again nitrogen has been regained.

In olden days the nitrogen balance in the soil was maintained quite adequately, with the nitrogen being removed as food and returned as compost and animal manure. But the greater demands of modern civilisation would soon strip the soil if nothing more were done than this. The need for food has become so great that it is no longer possible to let the soil rest; and though much sewage is now being recovered, enormous amounts are still finding their way to the sea. Hence the need for artificial fertilizers to be spread on the land.



What is the action of the bacteria?
Bacteria + Protein → ? → ? → ?
Why did one of the tubes not have any bacteria in it, and another have no casein in it?
What happens to bacteria if they are boiled?

A simple plan of the Nitrogen Cycle.

In Chile there are enormous deposits of sodium nitrate, a salt more commonly known as Chile saltpetre, which because of its nitrate content can be used as a fertilizer that is immediately usable by the plants. This deposit of the salt in Chile was not washed away into the sea because it occurs in a region where no rain falls. This explains the occurrence of sodium nitrate in other low-lying areas where it has been washed down by the rain.

Coal is yet another source of artificial fertilizer. Many millions of years ago today's coal deposits were vast swampy forests and, like any other plants, the trees in the forests contained proteins. Layers of the decaying vegetation became buried and great pressures made them what we know as coal. Although coal is chiefly carbon, it also contains some nitrogen. In the ordinary coal fire this goes straight up the chimney to be lost into the atmosphere, but it can be recovered as a by-product when the coal is being used to make coal-gas. The nitrogen is recovered from the coal-gas in the form of the alkali ammonia. Ammonia itself cannot be used as a fertilizer as it would upset the acid-alkali balance of the soil, making it too alkaline. It is converted into ammonium sulphate and sold as a fertilizer. It is not immediately available to the plant, for, first, bacteria must convert it into nitrates. Ammonium sulphate has a content of 21 per cent nitrogen. Ammonium nitrate is now becoming popular as a fertilizer as it contains 35 per cent nitrogen. Its nitrate part is immediately usable by the plant and its ammonium part becomes usable later. Ammonium nitrate is made from ammonia and nitric acid. The nitrogen of the air can be used to make fertilizers in two main ways. It can be made into ammonia. Here the nitrogen is separated from the air and mixed with three times its volume of hydrogen. The gas mixture is compressed and passed over hot iron which speeds up the reaction, and some ammonia is formed which is then made into the fertilizer, ammonium sulphate. The other method of turning the nitrogen of the air into fertilizers is an imitation of lightning. An electric arc is used in place of the lightning under carefully controlled conditions to manufacture nitric acid from the air. The acid is then converted into nitrate fertilizer. The snag here is the high cost of the enormous quantity of electricity needed. This process is used only where cheap hydro-electric power is available. Most nitric acid is now manufactured from ammonia.

2. Ecological Problems

Ecological Problems

If symbiosis is like marriage, then the wider aspects of ecology are like society. The place where you live is called your ENVIRONMENT and not only consists of inanimate objects like houses, roads, gas-mains, civic buildings and sewage-works, etc., but also of living things like postmen, bakers, butchers, bus-drivers, potatoes, lettuces, pigs and cows.

Similarly, a pond is not merely a hole full of water with air and light on top and waterproof rock underneath. It is the plants around the edge, the bacteria in and on the mud, and plants and animals floating in the water and on the bottom.

For an interesting example of ecology think about the problem of people living in a space capsule for a considerable length of time, perhaps a year. To help you to start, look back to the list of the requirements of a typical animal which we made earlier on. Or think about a problem with which some of you may be more familiar, that of camping with friends some distance away from the nearest village or farm.

Now let us try to unravel some of the problems concerning the inter-relations between organisms living in different environments.

In the pages which follow some information is given about a few environments and the problems which might confront someone who is looking at them for the first time.

The study of ecology

There is no one set method for studying ecology. You may prefer to look in detail at one particular species of plant or animal in one or a variety of environments, or, on the other hand, you may prefer to look at a whole range of animals and plants in a single environment. Whichever method you prefer, you must have a keen eye, the ability to make accurate records and to ask questions, a little biological knowledge, and a lot of common sense. Do not waste time trying to identify an animal or a plant beyond the class (in the case of an animal) or family (in the case of a plant) to which it belongs. It is much more interesting and profitable to find out how the organism feeds, how it gets the gases it needs, how it reproduces, how it distributes itself throughout its environment.

Suggestions for ecological investigations

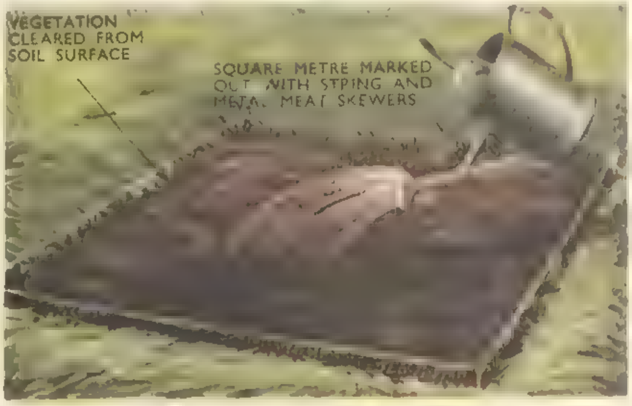
1. Estimate the number of earthworms in different types of soil

Earthworms can be 'persuaded' to come to the surface by applying 7 litres of potassium permanganate solution (1·5 grams dissolved in 1 litre, 4·5 litres = 1 gallon) to 1 square metre of soil surface from which the vegetation has been cleared. In about 30 minutes most of the worms will have appeared and can be counted.

Find two different areas and carry out the above procedure about ten times on each.

The results provide interesting material for discussion.

1. Is the variation between the numbers of worms from the samples from one area the same as or greater than the other?



2. Is it easy to tell that on the whole there are more worms in area *A* than in area *B*?
3. How many worms per acre are there in each area?
4. If there are more worms in one area than there are in another area can we find out why?
5. Do more worm-eating birds visit one of the areas?
6. Is the soil shallower or is it wetter, or has it a higher humus content in one of the areas?
7. Do worms move to a wetter soil or to one with a higher humus content? Could you set up an experiment to find out?

The answers to these questions and many others like them can be provided by simple experiments and careful observation.

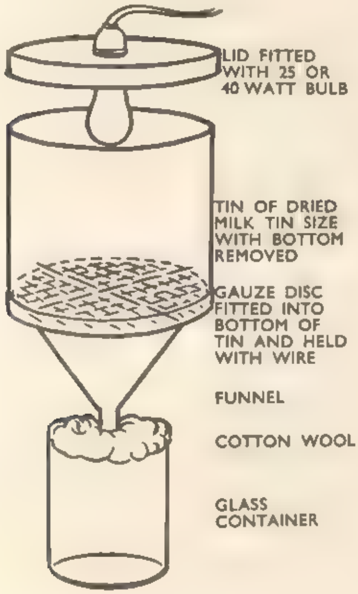
Here is a second investigation.

2. Sampling soil 'insect' populations

The collection of soil organisms, insects and other arthropods can easily be made by using a home-made Tülgren funnel.

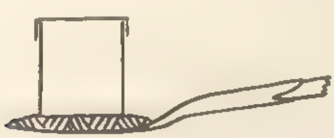
This apparatus depends on the fact that soil organisms move away from heat, light and low humidity.

The bulb provides heat and light and dries the soil. It should be used as follows:



1. Place tin on soil surface with a spare lid on its top with the gauze and supporting wires removed.

2. Slide a spade into the soil at the required depth under the tin as near to the horizontal as possible.

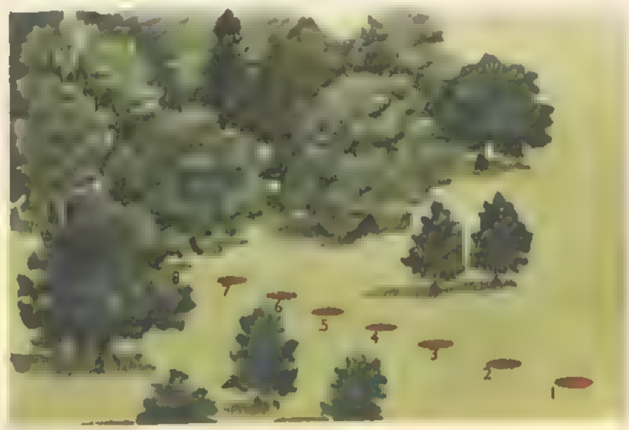


3. Press down on the tin until it touches the spade, then lift it slowly to extract a core of soil. Replace gauze and supporting wires.

4. Back in the laboratory remove the lid and replace the bulb. Mount the tin on the funnel.

The organisms may be observed and identified as they drop into the tube.

Samples of soil may be collected in a variety of places—for example, at the edge of a wood.



The animals can be roughly identified and numbers of types compared from the different samples. Try to invent explanations for the differences between samples, and then to test these explanations by experiments.

3. The relationship between light intensity and plant distribution

Another investigation is to examine the effect of light intensity on the distribution of plants in a wood.

Divide into several groups, each group having a photographic light-meter. Decide on three or four easily recognised species of plants and measure the light intensity where they occur. Does any pattern emerge from the results?

4. Activity in woodlice

There are several different types of woodlice to be found in Britain, and as they can be found quite easily in most areas they are particularly suitable for ecological experiments. Despite their cryptozoic (hiding) life they are really quite interesting creatures.

Try to find out how active they are by the following method.

Find a colony of woodlice under stones, old wood, etc., and collect as many of the same kind as you can from the colony. Repeat this for other colonies, keeping your collections separate.

Take the collections back into the laboratory and mark each of the woodlice on the back with a spot of quick-drying paint, using a different colour for each of the colonies.

Now release the woodlice in the places where they were collected.

You are now in a position to find out whether the woodlice tend to remain in the same area or if they move about and, if so, how far they move, and also whether they move about by day or by night.

You can do this by returning to the collecting areas the day after you released them, and on several days after that; if possible, both in the mornings and in the evenings.

It is not necessary to pick the same kind of woodlouse from all the colonies; indeed if you use different ones, then you will probably find that some kinds tend to occupy one type of environment and that others pick quite different places.

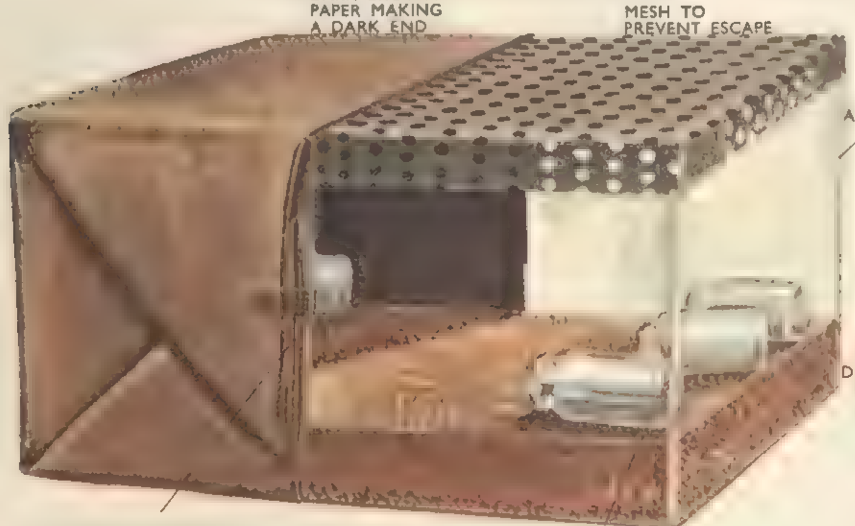
Using a large container such as an aquarium tank, could you set up an experiment in the laboratory to find out whether a particular type actively chooses a certain place to live (habitat)? Here is one idea.

Release quite a large number of woodlice in the middle of the sandy floor and watch what they do and where they go. Do they go to the light end or to the dark end of the tank? When they have all stopped moving about lift out the jars and count how many woodlice there are in each one. You can repeat the experiment several times in order to get a reliable result, and you can also repeat it with different kinds of woodlice.

Afterwards, from your results, can you say whether the woodlice distributed themselves at random about the tank or did they tend to congregate in certain places? Were these places dark or light, and were they very wet, damp or dry?

After this the experiment can be tried again to find out, for example, whether they prefer leaves, stones, soil or moss, etc.; also to find out if they like a warm habitat or a cold one, and to test any other ideas that you may have about what factors govern where woodlice live.

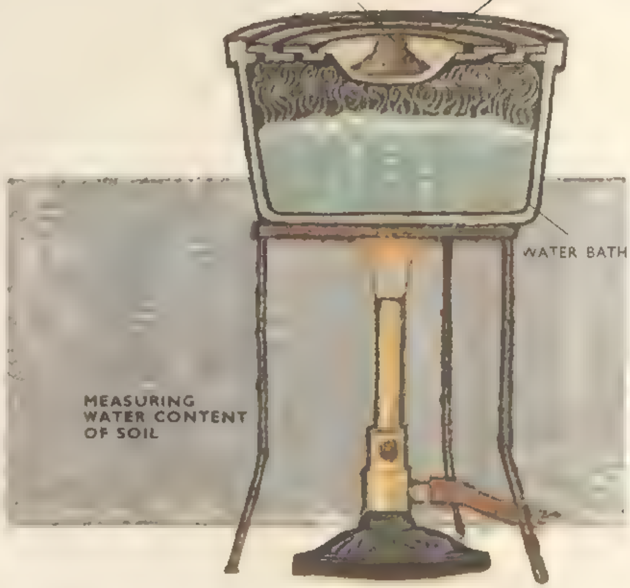
Apparatus for finding out the preferences of woodlice.



3. Different Environments

Different Environments

As ALL animals are ultimately dependent on plants, and as most plants grow in soil, soil and its contents are obviously of fundamental importance to us. What can we find out about it by means of a few simple experiments?



The soil and experiments on the soil

Soil might be thought of as consisting of 'skeleton' and 'flesh'.

The skeleton is the mineral particles weathered from older rock. Are all these particles the same size, or if they differ are the proportions in one soil sample the same as those in another sample? You may find this out by shaking a sample of soil with some water in a jar. When all the soil has settled (the dense particles fall to the bottom first) the thicknesses of the layers can be measured and a comparison made with other samples.

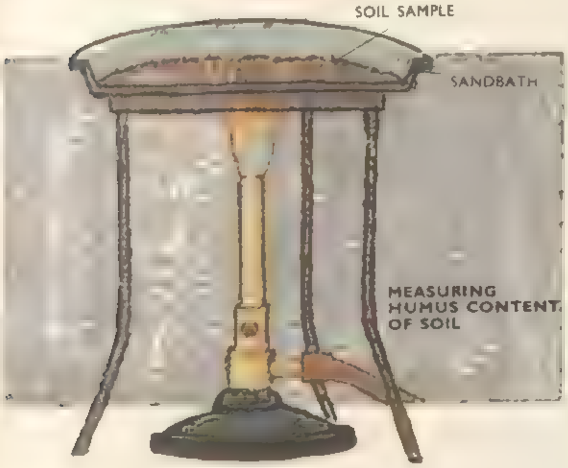
The flesh of soil is the water, air, mineral salts, and decaying organic matter (humus) coating the particles or filling in the spaces between them. If the soil particles are large and round, as in a sand, then the spaces between them are also large and can hold a lot of 'flesh'; and if the particles are small and flat, as in a clay, then the spaces are small and cannot hold much 'flesh'. If we know whether the soil is coarse like a sand or fine like a clay, then we can guess at the amount of 'flesh' that it contains, but can we measure the amount more precisely? The amount of water is fairly easy to measure. All we must do is to weigh a sample of soil in an evaporating basin, heat it on a water-bath, weighing it at intervals until it reaches a constant weight, and then from the difference between the original and final weight the percentage of water can be calculated.

This dry soil can then be used to measure humus content. First it must be tipped onto a metal-tray, then heated strongly until it stops smelling like a bonfire (why should it smell like that?), and finally weighed when the tray is cool enough to handle.

Again from the difference between the dry weight and final weight the humus percentage can be calculated.

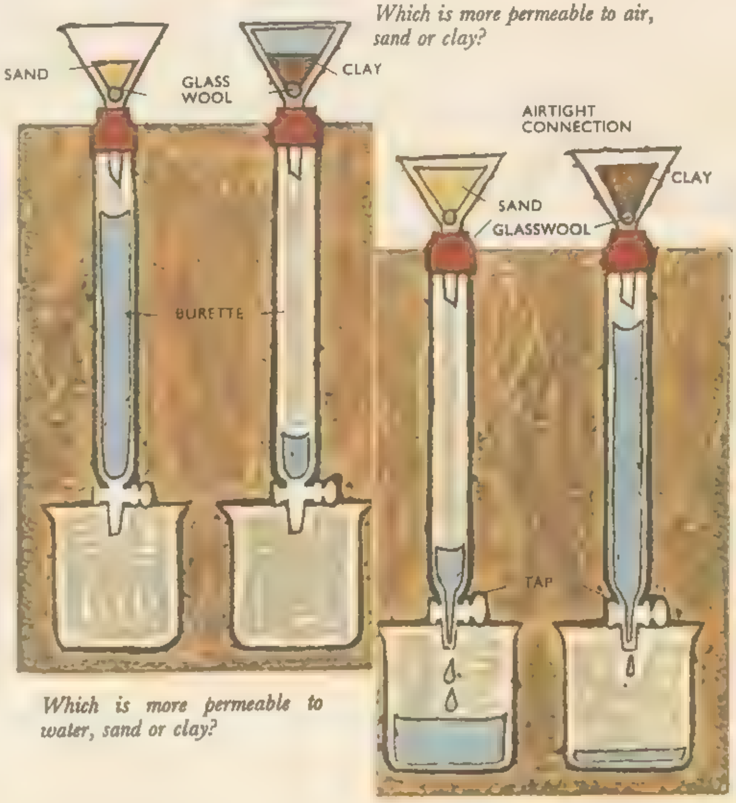
A soil sample is simply analysed by shaking it up with water in a large jar. The heavy particles fall to the bottom first. The percentage of different sizes of particles can then roughly be estimated. Alternatively carefully graded sieves can be used.

(Left) The water content of a soil sample can be estimated by heating a known weight of soil in an evaporating dish supported on a water bath. The soil is reweighed at intervals until identical results are obtained. The difference between the original weight and the final weight gives the percentage of water present. (Below) The dry soil is then heated slightly on a sand-tray. Organic matter is converted into CO_2 and water. This further loss in weight represents the amount of humus present in the soil sample.



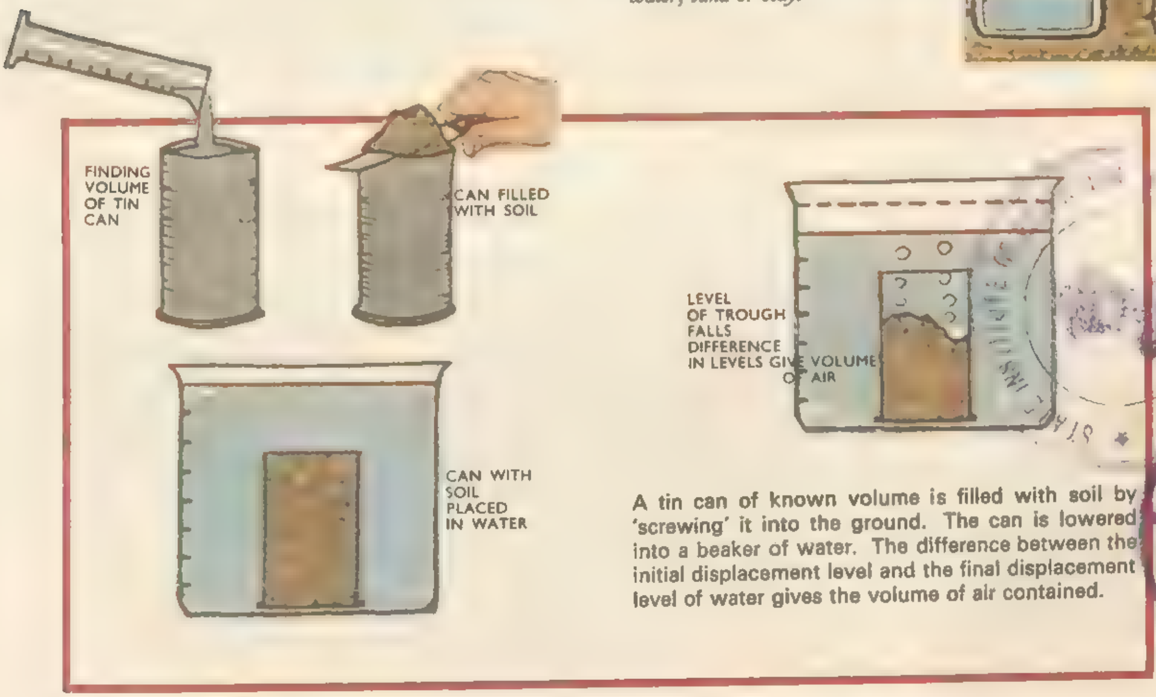
Measurements of the permeabilities of various soils to water and air are interesting and help to give a fuller insight into soil properties. Following are two examples which you might try for yourself.

Which is more permeable to air, sand or clay?



Which is more permeable to water, sand or clay?

The amount of air in a sample of soil can be estimated in various ways. Here is one of the easiest methods.



A tin can of known volume is filled with soil by 'screwing' it into the ground. The can is lowered into a beaker of water. The difference between the initial displacement level and the final displacement level of water gives the volume of air contained.

So far we have only considered the non-living aspect of soils. If you refer back to the section on ecological investigations there are some experiments there on soil organisms; but just to complete this section of simple soil experiments here is one to set up to see if small soil samples contain living organisms.

The bubble will move to the left if organisms are present in the soil because they will absorb oxygen. What is the purpose of the caustic soda? Try this with different soil types – for example, a clay and a very leafy soil from under a tree.

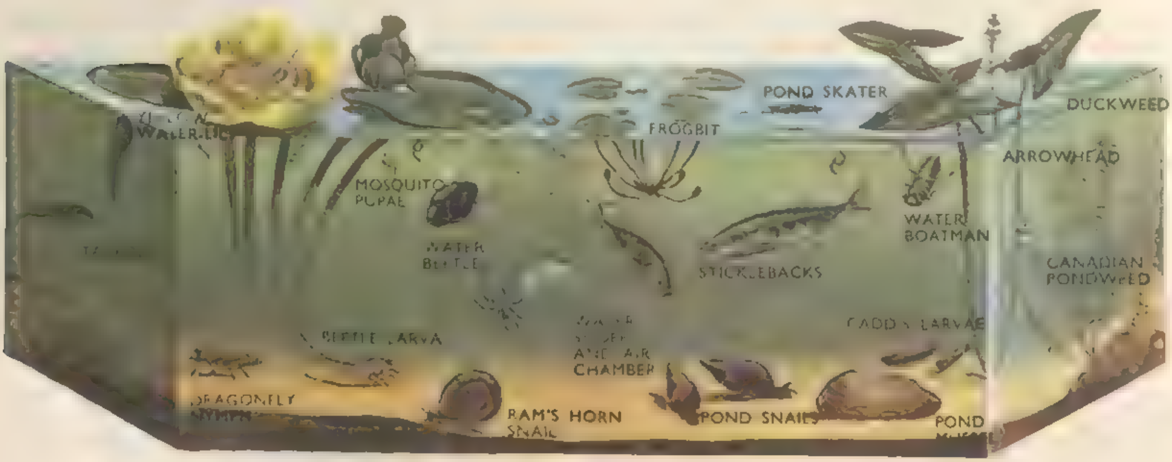
Pond life

Rain falling upon the land runs over and through the soil and finds its way into streams and ponds. During its journey, the water dissolves a great deal of material and carries more in suspension. These materials include nitrates from decaying organisms, mineral salts from the rocks, and oxygen and carbon dioxide from the atmosphere. These are vital and valuable plant foods and it is not surprising that plants have colonised fresh water wherever possible and that the plants have been closely followed by animals. Life in fresh water presents a number of problems that have been solved in various ways. Running and still water present very different problems and support different types of community.

The natural history of a pond depends very much upon the local geology. Ponds in regions of volcanic rocks or on sandy heaths are notably poorer in vegetation and animal life than ponds fed by water from chalk or limestone regions. The acidity of the rocks (and therefore the water) is also important in determining the future succession of vegetation in the lake or pond.

A pond or lake with rocky shores provides little roothold for vegetation, but a pond in clay or river deposits usually contains abundant plant life.

The plants provide food and shelter for the animal inhabitants and also, through the process of photosynthesis, provide oxygen which dissolves in the water. The dissolved oxygen is very important, not only for the living organisms but also for the decomposition processes on the floor of the pond. The weediest ponds are usually the ones with the most animal life, but they



Some animals and plants to be found in a pond.

Various insects and the methods by which they obtain oxygen from the surface.

also produce the most waste material. Plants can grow only in the upper layers where there is light. A deep or very dirty pond will have no plants at the bottom and, unless there is a good circulation of water, very little oxygen. The processes of decomposition will quickly use up what oxygen is present, and little animal life will survive. Ponds under trees are rarely of any interest to the naturalist. Shade prevents plant growth and the accumulation of leaves uses up what oxygen can dissolve in the water. Such ponds are black and barren. Only those animals, such as the Rat-tailed Maggot, which can feed on the foul material and get oxygen from the surface can survive.

The animal life

Representatives of almost every major group of animals can be found in fresh water, and every region of a pond has its characteristic inhabitants. The surface of the water, although no different in composition from the rest, acts like a very thin skin and is able to support some small animals. The pond-skaters and whirligig beetles are often found skimming across the surface in search of unfortunate insects that have fallen on the pond. Whirligigs have divided eyes: the upper parts are thought to be able to see in the air and the lower parts down through the water. On the underside of the surface film black planarian worms glide along, small snails hang and mosquito larvae take in their air supply.

Obtaining oxygen is one of the main problems to be overcome by animals living in the water. Small animals, such as Hydra and water-fleas, get sufficient by simple diffusion from the water. Larger animals require special breathing organs. Fishes have *gills* which absorb oxygen directly from the water. Some insect larvae also have gills, e.g. dragon-fly and caddis-fly larvae. These animals can survive only where there is an adequate oxygen supply in the water. Many animals, however, have re-invaded water from the land and are still air-breathers; they have to come to the surface periodically for air. Such animals include water-beetles, water-bugs, some fly larvae, pond-snails and the semi-aquatic mammals such as beavers and otters. The air-breathing habit means that the animals can live in poorly oxygenated water – provided that there is sufficient food.

If a pond is to be investigated a careful plan must be made rather than attacking it in a random fashion. How might one start, what should one look for, and what tools might be required?

Collecting equipment

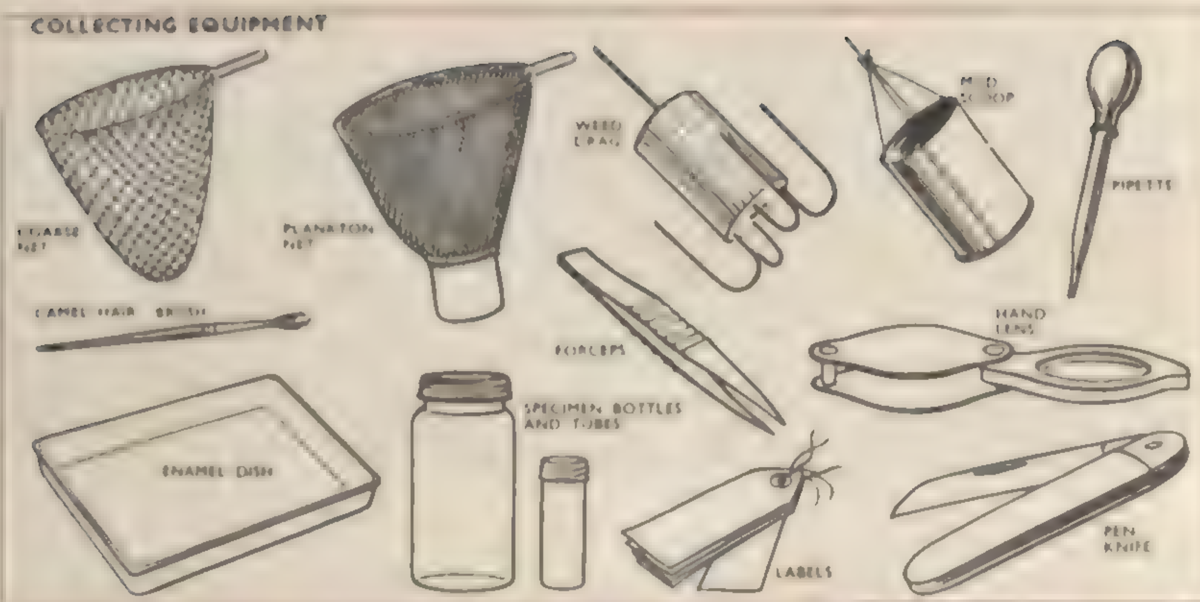
These are some of the things required for pond investigations, and, as you can see, all can be improvised with the exception, perhaps, of the hand lens and forceps.

The most important tools are your eyes; the first thing to do in any ecological investigation is to look.

A suggested plan of work

Look first at the plants in and around the pond. Can the places where they grow be put into separate divisions? Here is one idea:

1. The damp ground around the pond.
2. The edge of the water.
3. In the water but attached to the bottom.
4. Floating in the water.



Common plants found in and around ponds.

Examples of plants to be found in these places include:

1. Meadowsweet, Great Willow-herb, Sedges, Common Rush, Purple Loosestrife.
2. Yellow Iris, Marsh Marigold, Reedmace, Common Reed, Skullcap, Gipsywort, Water-plantain.
3. Water-lily, Arrowhead, Water-crowfoot, Starwort, Water-milfoil, Canadian Pondweed
4. Duckweed, Frogbit, Water-soldier.

Finding and identifying pond animals is usually rather more difficult and this is where the nets are useful. Do not use the nets at random, but choose a particular area of the pond, collect from it for a time, putting your catch into labelled containers, then change to a different area and use fresh containers.

Some areas for finding animals are:

1. On or just under the surface.
2. The upper layers of the water.
3. The lower layers of the water.
4. On the mud, stones, etc., at the bottom of the pond.

Animals which live in these areas include.

1. Pond-skaters, whirligig beetles, various larvae, e.g mosquito larvae
2. Plankton, water-fleas
3. Fish, frogs, toads, newts, tadpoles, water-boatmen, various water-beetles.
4. Leeches, flatworms, water-snails, dragon-fly larvae, caddis-fly larvae, pond-mussel.

The presence of other animals, not actually in the water, but associated with it, such as birds and adult dragon-flies, may also be recorded.

The plants can usually be identified without removing them. However, if it is necessary to take some away for examination, then the smallest possible amount should be removed. The animals, on the other hand, can only be seen easily in dishes or bottles. Never collect more than you need, as they often die quite quickly once out of the pond.

Having collected and identified some of the organisms from the pond, is that all you can do? Have you got an idea as to how a pond works? How can you find out? One way is by observation, and by asking yourself questions.

Animals that live in ponds

Here are some questions to guide your observations on an animal you have collected:

How does the animal move?
How does it obtain its oxygen?
How does it feed?
What does it eat?
Does it like light or shade?
What enemies has it got?
Is it associated with any particular plant?

Life in rivers and streams

The character of a river changes considerably between its source and its mouth: in one stretch a raging torrent cutting its way deeply into rock and carrying boulders and stones before it, in another part flowing quietly and smoothly through its plain, meandering to and fro, slowly carving away its banks in some parts and adding to them in others. If it enters the sea, then its salinity will vary from one part of the estuary to another and with the state of the tide: when in flood it will be less saline, and conditions in its upper reaches will be very different. A torrent near its source may be reduced to a trickle or dry up altogether during droughts. The bed of the river may be of hard smooth rock, it may be littered with boulders, or covered in gravel or mud.

The speed of the current and the type of bottom deposit, therefore, vary from one part of a river to another. They are important factors which severely limit the distribution of the animals and plants within it. Few plants can gain a foothold where the current is swift and where sand or mud is not deposited. Of the animals, strong swimmers and flattened and streamlined forms with means of clinging to stones and the like are best suited. On the other hand, where the current flow is negligible, sand and mud will be deposited, plants will have sufficient material in which to root, and a variety of animals (especially burrowers) will be able to make a living.

Chemical factors are also of importance. Occasionally a stream may be acid and poor in dissolved salts – barriers that few animals are able to overcome. Where large quantities of sewage are piped into a river, decomposition may so deplete the oxygen content that all plants and animals are killed.

Numerous attempts have been made to describe a typical river, but this is extremely difficult, for each has its own characteristics. Some may rise on a mountainside, and the headstream, though not containing much water, will be extremely fast-flowing. Others may appear as springs at the bottom of a chalk hill and from there flow gently to the sea. However, one classification of the habitats is described below. Some rivers lack some of the divisions, and local conditions (e.g. waterfalls) may upset the sequence. The five divisions are: *Headstream*, *Troutbeck*, *Minnow reach*, *Cyprinoid reach* and *Pleuronectes reach* (the latter is present only in rivers that enter the sea).

Headstream

This, the upper region of the river or stream, generally occurs in high ground. Usually it is short with a shallow, fast-flowing trickle of water from the source. This may be a spring or melting ice, for example. Its bottom is generally rocky and, although it is shallow, its temperature is low and it has little power or erosion.

Mosses and liverworts thrive in the damp conditions. Despite the fact that food is relatively scarce, the headstream has a surprisingly varied population. There are numerous protozoans and wheel animalcules (rotifers). Of the crustaceans, the fresh-water shrimp (*Gammarus pulex*) is often found. It 'prefers' shallow running water, rich in oxygen, and is found only in ponds that have streams entering and leaving. The water-louse (*Asellus*), on the other hand, seems to 'prefer' still or slow-moving water, and is common in the more sluggish parts of rivers and ponds.

The young stages (nymphs) of a number of insects are adapted for life in fast-moving water. Common are the nymphs of some mayflies. The adults are extremely short-lived – from a few hours to two or three days – but the nymphs may take two years from the time of hatching to reach the adult stage. Many adult mayflies fall victim of fish, especially trout. The artificial 'flies' of trout fishermen are models of several species of mayfly. Older nymphs have gills along each side of their body. These obtain oxygen from the water. *Baetis* is frequently encountered.

A few caddis-fly larvae that build light cases are encountered – *Stenophylax* and *Agapetus*, for example. The latter's case has a flat side, with two openings in it, and a curved side. It is built of tiny stones. *Agapetus* hides under stones.

Nymphs of the stone-flies *Leuctra* and *Nemoura* are frequently found. They are not good swimmers and live mainly by crawling on the undersides of stones, pressing their flattened bodies close to the stone surface so that the water current does not lift them up and wash them away. Besides the snail, *Limnaea trunculata* (or dwarfed limnaea), a number of so-called *relict* forms may be found. These are animals which were of widespread occurrence during the Ice Ages. As the ice receded, however, the number of habitats in which they could survive was seriously reduced. They now occur locally in mountain streams and springs where conditions are sufficiently cold and moist. Examples are the flatworms, *Planaria alpina* and *Planaria cornuta*.

In moist ground along the edges of the headstream the larvae of several species of crane-flies or daddy-long-legs are found.

Troutbeck

The troutbeck is a more permanent channel downstream of the headstream. The volume of water is greater and the current is swift. The bottom is either rocky or strewn with stones and boulders, and may also contain some gravel. Erosion is considerable and there may be some deposition at the bends. The water is extremely cold and the quantity of dissolved oxygen high. There is little vegetation but, where bottom deposits occur, water-crowfoot may gain a foothold. Plankton is absent and the nekton includes the trout, miller's thumb (free-swimming creatures) and roach.

The nymph of the mayfly, *Ecdyonurus*, is broad and flat. The strong claws at the tips of its large flat limbs enable it to cling tightly to the surfaces of stones. Stone-fly nymphs – for example, *Perla* and *Isoperla* – are frequently found. Several web-spinning caddis-fly larvae inhabit the troutbeck. *Hydropsyche* builds a net of silk threads on the underside of stones. Plants and animals caught in the net are seized by the larva and eaten: *Stenophylax* and *Agapetus* also live in this region. Larvae of the black-fly (*Simulium*) inhabit the troutbeck, attaching themselves by means of a tail sucker to stones in the centre of the stream where the current is fastest. They can also spin strands of silk, just as a spider can, to avoid being washed away, and so they regain a lost position. They have a prominent pair of mouth-brushes with which food material is filtered from the water. The length of larval life varies from a month to six months. Each larvae forms a tough, brown cocoon before pupating, and this is attached to stones or plants. The adult emerges after only two or three weeks.

The wandering snail, *Limnaea pereger*, common also in ponds, is frequently found, as is the river limpet, *Ancylastrum*. Leeches, too, and flatworms live in the troutbeck. The animal population of the troutbeck, therefore, is similar to that of the stony-beach community of a lake large enough for there to be some wave action.

The troutbeck is the home of oxygen-loving animals. The speed of the current is such that they have to cope with considerable stresses. All are beautifully adapted, either because they are streamlined or flattened (e.g. *Ecdyonurus*), they have suckers or filaments for adhesion (e.g. *Simulium*), they hide under stones (e.g. miller's thumb), or they are powerful swimmers (e.g. trout).

Minnow reach

The minnow is the characteristic animal of this region. The current is slacker, erosion less pronounced and the fall of the river is less rapid. There are usually a number of stones on the bottom, for the coarser grits are deposited. These act as barriers to other material floating downstream, and pools often form at the edge of the stream, thus encouraging the growth of water-crowfoot. If it encroaches at the edge of the stream, finer particles will be deposited, though the bottom never has an all-over covering of mud. The water temperature varies considerably with the time of year, often being high at the edge. A rich oxygen supply may also be present, but it is never plentiful enough for the species of black-fly that inhabit the troutbeck.

The wandering snail, pea-shell cockle (*Pisidium*), fountain bladder snail (*Aplecta*), and ram's-horn snails (*Planorbis*) are common molluscs. There are many young stages of caddis-flies and dragon-flies, and numerous flatworms. In the pools, and at the edges, there may be sufficient sediment for some burrowing forms. The nymphs of the mayfly *Ephemera* live in burrows, but the water has to be sufficiently muddy for the light intensity to be low. Light is harmful to them. Some of the familiar bloodworms (larvae of the midge *Chironomus*) build tubes of mud and feed on debris in the bottom deposit. Larvae of the alder-fly (*Sialis*) are often found and water-bugs may occur if the water is fairly slow-moving. Salmon spawn where there are beds of gravel, and on bends, where deposition is sufficient, the ammocoete larvae of lampreys often live.

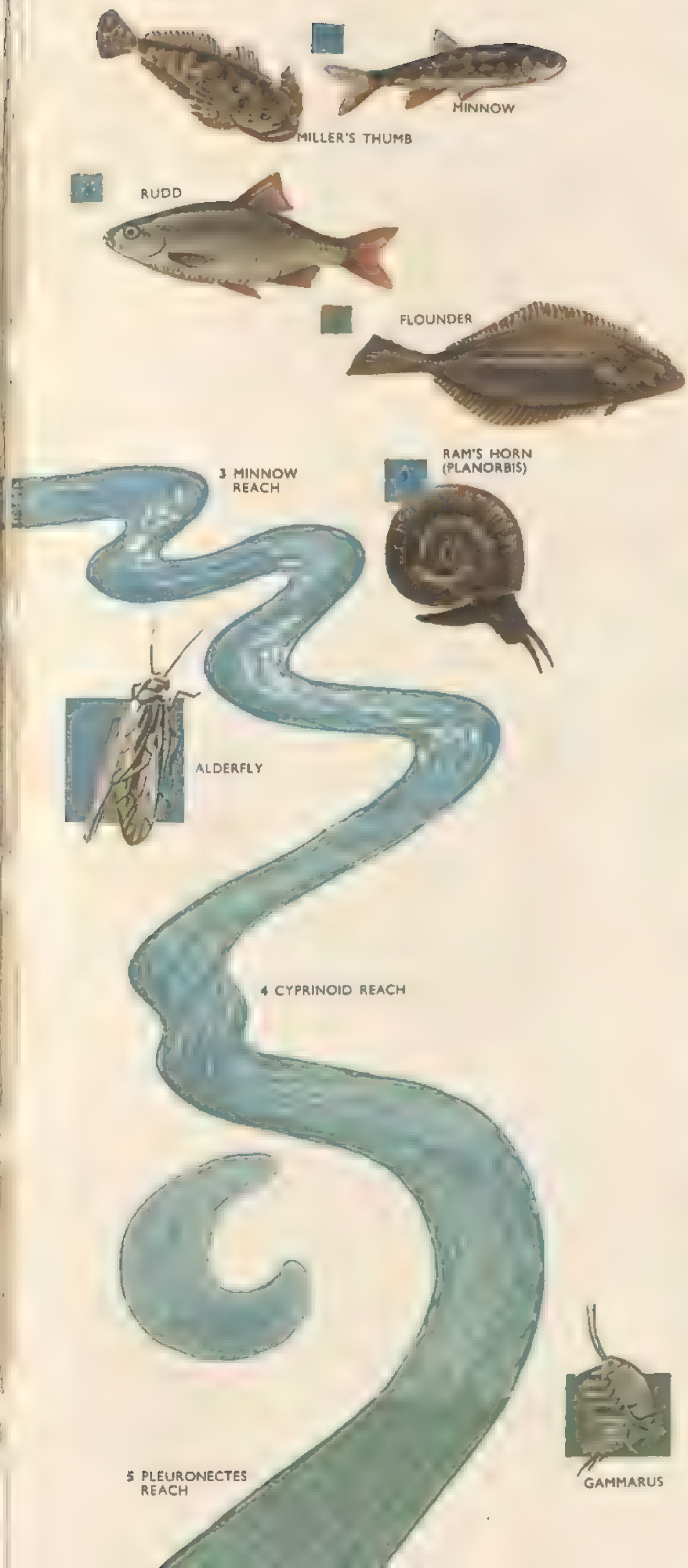
Cyprinoid reach

The current of this region is slow and there is considerable deposition. The river meanders and gravel carried down in floods is deposited on the slack-water side of bends. The stream slowly changes course by continual deposition and erosion, often leaving ox-bow lakes. Its temperature is variable.

Water plants are abundant, especially at the edges, and often the surface may have a complete covering. Reeds occur where the banks slope gently. In the centre of the river typical running-water forms live, but the edges and quiet backwaters have a lake-like fauna. Burrowing forms often predominate where the water is turbid (e.g. *Ephemera*, various worms – *Nais*, *Tubifex* – and bloodworms). Molluscs include species of *Pisidium*, *Sphaerium* (orb-shell cockle), the *swan mussel* (*Anodonta*) and fresh-water mussel (*Unio*). Plankton is not common and the nekton consists almost entirely of fish of the family Cyprinidae such as carp, bream, tench, roach and rudd.

The Cyprinoid reach is a region of great variation, often upset by man's influence, as in areas where meadow farming is practised and the stream is channelled off over a wide area. The backwaters tend to have a richer fauna.

1 HEADSTREAM
BAETIS
DWARFED LIMNAEA
2 TROUTBECK
2
TROUT
PLANARIA ALPINA
1
ANCYLASTRUM
2
ECDYONURUS
2
EPHEMERA
3
TUBIFEX IN MUD TUBES
4
HYDROBIA
5


MINNOW
MILLER'S THUMB
RUDD
FLOUNDER
RAM'S HORN (PLANORBIS)
3 MINNOW REACH
ALDERFLY
4 CYPRINOID REACH
5 PLEURONECTES REACH
GAMMARUS

Pleuronectes reach

This is the tidal region of a river. Such factors as temperature, salinity, and current direction vary tremendously.

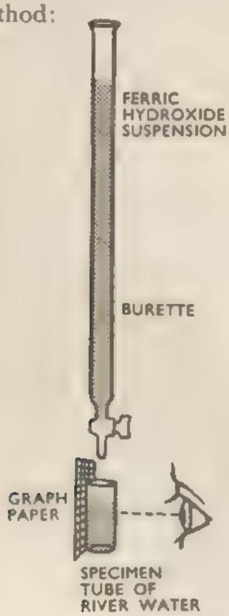
Of the animal community only a few species are native to slightly salty (brackish) water. They include two species of the fresh-water shrimp *Gammarus duebeni* and *G. zaddachi* and a flatworm (*Procerodes*). A brackish water form of Jenkins' spire shell (*Hydrobia*) is also common.

The region is named after the flounder (*Platichthys*), a member of the family *Pleuronectidae*. This fish abounds in muddy estuaries, leaving the rivers for the sea in the spring in order to breed. This fish and many others pass through the Pleuronectes reach on their way from the river to the sea, or in the reverse direction, to breed – for example, the trout, eel, salmon and smelt. Several species of *Coregonus*, relatives of the salmon, also frequent brackish water.

Because of its size a river provides a very complex and large study of an environment. It should really be treated as a succession of different environments, and the method of tackling any particular part of a river is the same as tackling a pond. The main difference is in the organisms to be found. The same equipment can be used, although widths and depths of water make collecting more difficult and often more dangerous.

Some useful long-term experiments can be done on rivers concerning the measurements of physical factors such as temperature, rate of flow, depth, and clearness of the water. Rate of flow, temperature and depth can easily be measured, but transparency is a little more difficult.

Here is one method:



The ferric hydroxide suspension should always be of the same concentration, and well shaken.

The graph paper should always be of the same type, the specimen tube always of the same diameter, and the same amount of river water must always be used.

How much ferric hydroxide suspension must be added before the lines on the graph paper cannot be seen? This amount can be used as a measure of turbidity and can be plotted on a graph with the other measurements.

By collecting plants and animals at intervals can you find out how the numbers and types vary with the variation in depth, rate of flow, etc., and how these vary with the seasons and with the rainfall?

The sea and sea-shore

About two-thirds of the world's surface is covered by the sea. This means that there are something like 140 million square miles of about 12,500 feet average depth, so here is an enormous volume of water available as a home for fishes and other animals. In reality the seas provide a number of different habitats, each with its own collection of animals, and perhaps plants – habitats such as the sea-floor, the high seas, and the sea-shore.

The only part of the sea which is normally accessible to us is the shore, so really we must confine our attention to that.

The type of shore varies enormously, even around a small country like Great Britain. The unending battle between land and sea results in erosion at one point and deposition at another. Where erosion takes place cliffs develop, with rocky shores at their feet. The material eroded from the land is transported by off-shore currents and deposited elsewhere. Pebbles and shingle are deposited first, in the neighbourhood of the erosion site. Sand, made up of finer particles of silica and other material derived from many types of rock, is transported farther by the water than are the pebbles. In very sheltered inlets fine mud may be deposited, forming mud-flats at low tide. This is especially noticeable in and around estuaries. So shores may be divided into the following types: rocky, shingle, sandy, muddy. Of these types the one which perhaps most rewards study is the rocky shore.

If a section of shore is looked at at high tide then it is most frustrating, as most of the animals and plants will be found to be under water, out of reach; so obviously the best time to look is at low tide. Does the tide rise and fall the same amount each day, or is one day better than another for examining the shore?

If you can get hold of some tide tables in an almanac, you will find that the tide heights, times and dates are given.

Here is an extract from some tide tables for the month of September 1967 for the port of Portsmouth.

Date	A.M. hr. min.	Height feet	P.M. hr. min.	Height feet
1	9 57	12·5	22 14	13·1
2	10 49	13·6	23 03	14·0
3	11 34	14·6	23 47	14·7
4	—	—	12 15	15·4
5	0 27	15·3	12 57	15·9
6	1 08	15·7	13 40	16·3
7	1 51	15·9	14 25	16·4
8	2 36	15·9	15 10	16·2
9	3 23	15·5	15 55	15·6
10	4 11	14·7	16 41	14·7
11	5 05	13·7	17 35	13·6
12	6 15	12·6	18 48	12·7
13	7 50	12·1	20 20	12·3
14	9 22	12·4	21 39	12·6
15	10 27	13·2	22 37	13·2
16	11 14	14·0	23 21	13·8
17	11 51	14·6	23 58	14·3
18	—	—	12 24	15·0
19	0 30	14·6	12 56	15·2
20	1 02	14·8	13 27	15·2
21	1 34	14·7	13 59	15·0
22	2 07	14·6	14 30	14·8
23	2 40	14·3	14 59	14·5
24	3 11	13·9	15 27	14·0
25	3 43	13·3	15 58	13·4
26	4 20	12·6	16 38	12·6
27	5 10	11·9	17 39	11·9
28	6 33	11·4	19 08	11·6
29	8 11	11·8	20 37	12·1
30	9 25	12·8	21 43	13·1

From this information plot either the morning or the afternoon tide heights against the date.

Normally the tide goes out as far as it comes in, i.e. it falls as much below the mean sea-level as it rises above it; so if you know when the highest high tides are, then the lowest low tides are almost at the same time.

In September 1967 the phases of the moon are as follows: New Moon on the 4th, First Quarter on the 11th, Full Moon on the 18th, and the Last Quarter on the 26th. If you know the phases of the moon for any month of the year, could you predict the best times for examining a section of shore?

When a rocky shore is looked at for the first time the range of animals and plants is often bewildering. Where does one start?

As with the pond, perhaps the best thing to try to do is to find a pattern in the distribution of the plants, or seaweed.

SEAWEEDS FROM A ROCKY SHORE

Seaweeds are Algae (flowerless plants), and on a shore three main types can be found: green seaweeds (*Chlorophyceae*) brown seaweeds (*Phaeophyceae*), and red seaweeds (*Rhodophyceae*).

The green seaweeds are often found on the upper parts of the shore where there might be fresh water running over the rocks, and where there are pools at about high-tide level. Spray from the waves will keep the water in these pools salty to some extent. Two common green weeds are *Enteromorpha* and *Ulva* or sea-lettuce, so called as it is sometimes collected and used for food.

SEAWEEDS FROM A ROCKY SHORE (continued)

The brown seaweeds are the commonest and the most important plants of the shore. The green chlorophyl is masked by a brown pigment called fucoxanthin. Some of the brown algae are very large and usually consist of a holdfast, or root, a stalk, and a blade or leaf-like structure. Some species can withstand more exposure to air than can others, and therefore these weeds show a definite zonation on the shore. Those that can stand the greatest exposure are found on the highest part of the shore where they are covered by water for only short periods each day. *Pelvetia canaliculata* is one of the upper-shore species. Lower down various wracks (types of *Fucus*) occur. The commonest of these is *Fucus vesiculosus*, the bladder-wrack, so called because of the numerous air-bladders in the fronds. Another common species is the serrated wrack (*Fucus serratus*), found below the bladder-wrack on the shore. It has no bladders but the margins of the fronds are toothed, or saw-edged.

The oar-weeds or kelps (types of *Laminaria*) grow around and below low-tide level. The fronds may be many yards long and they are attached to the rocks by a very strong holdfast. Laminaria fronds are often washed up on the shore and are used as a sort of weather prophet. The dried fronds readily take up moisture from the air and can thus indicate to some extent the humidity of the air.

Bootlace weeds and thong weeds (*Himanthalia*) are very long and thin. They grow from small button-like holdfasts often in association with the kelps at low-tide level.

The red seaweeds are usually much smaller than the brown weeds and many are constructed in a different way. Instead of the flattened fronds of the brown weeds there are delicate branched filaments, or some may be more leaf-like. The red colour is due to the pigment phycoerythrin. These plants grow in rock pools and on the rocks at and below low-tide level. They extend into deeper water than do the brown weeds, for the red colour enables them to absorb light more efficiently. Some of these red weeds form skeletons around themselves of calcium carbonate (e.g. *Corallina*) and in tropical seas may be important contributors to coral reefs.

All these weeds are fairly easy to identify, and because of their obvious zonation they can often be used as tide-level indicators.

You will see that five tide levels have been named in the illustration below. The very highest and lowest tides are called Spring tides (N.B. they do not only occur in the spring), the smallest high and low tides are called Neap tides, and in the middle is the average or Mean Sea-level.

If you know where you are on a shore in relation to the tide levels, then the study of the animals is made much more interesting.

Some of the more common animals that one can find on a rocky shore are shown overleaf.

Most of these can easily be identified, and in searching for them the factors which influence their distribution will seem to be most complex. Here are some points to think about:

Is a particular animal always found at the same level on the shore?

When the tide falls and animals are exposed, what must they protect themselves against?

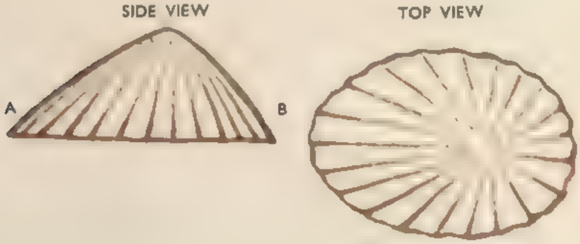
How do the animals feed: are they filter feeders, grazers, or carnivores?

Are any of the animals associated with any particular sort of weed? (Examine Laminaria fronds carefully.) If a number of one particular type of animal (e.g. Dogwhelk) is marked with paint and moved to another level on the shore, will it tend to return to its original position? If it does, how do you suppose it finds its way back?

Look at the Limpet, Patella, and observe how closely it fits the rock. Has it worn away the rock to fit its shell, or has its shell grown to fit the shape of the rock?

The Limpet is a grazing animal, it feeds on the fine green-grey vegetation on the rock surface. Try to find where the rock has been stripped of vegetation around a Limpet; this is its grazing area. Does it feed at night or during the day, when the tide is in or when it is out? Does it always return to the same place?

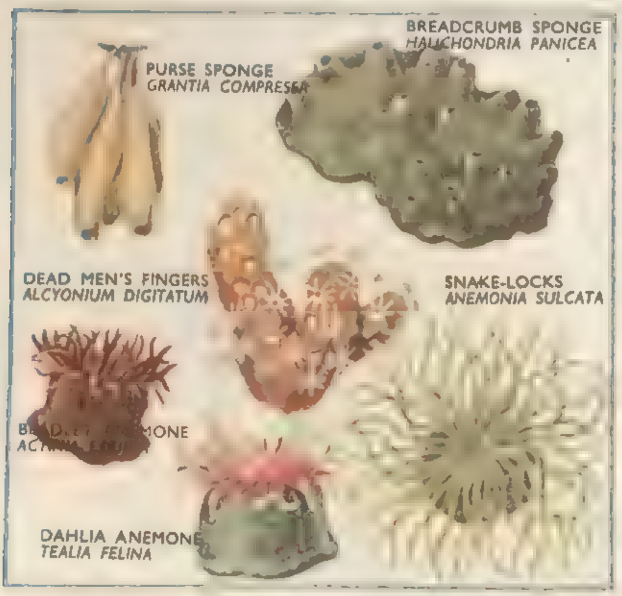
How do animals in exposed places withstand the buffeting of the waves? Again look at the Limpet. It looks like this:



The Limpet (*Patella*).

Would it be more streamlined if it pointed side A to the waves or side B? Does it do this? Your answer can easily be tested by observation.

These are just a few questions to start thinking about; many more will occur to you as you try to answer them – but remember all the time that the basic idea is to find out not just about the organisms themselves but how they live together, assisting one another or eating one another in the one environment.



Animals of the sea shore.

4. Can the Earth Produce Enough Food?

Can the Earth Produce Enough Food?

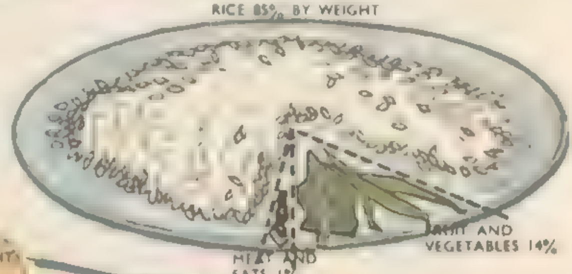
In 1840 the world's population was about 1,000 million. It rose to 2,000 million by 1930. By 1960 about 3,000 million people inhabited the Earth, and it is estimated that the population will reach 6,000 million by the year 2000 A.D. These extra people will need food and homes, both of which make heavy demands upon the land. Hunger and malnutrition are serious problems in Africa and Asia today. What of the future? Can the Earth support a further 3,000 million people?

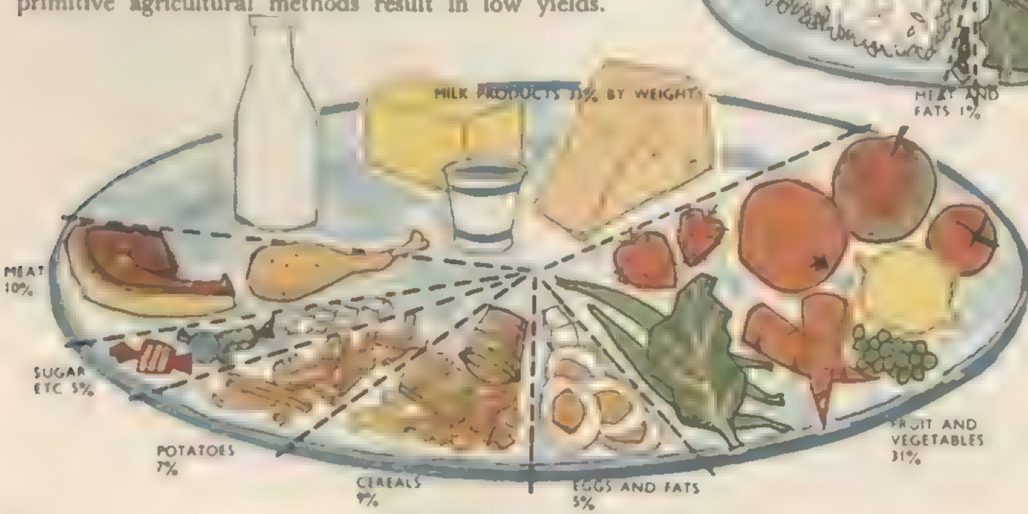
The answer to this is a firm 'yes'. At the present time there are about four acres of cultivable land per head of population. The rest is too dry, cold or mountainous. Of the four cultivable acres only about one is cultivated, and that often inefficiently. If the whole acreage were farmed and forested properly the Earth could support three or four times its present population. New towns will, of course, have to be sited on land unsuitable for agriculture or of low agricultural value. Although the world figure is about four acres of cultivable land per person, the figures vary from country to country. Canada has something like 20 acres per head of population while India has only one. Britain and Japan – both densely populated countries – have even less cultivable land per head. Political barriers will have to come down to enable the producer-regions to supply the consumer-regions. However, this can be no more than a short-term measure – surpluses will not always be available.

The present food problems in Asia and Africa are due largely to a lack of technical knowledge and financial resources in the countries concerned. The primitive agricultural methods result in low yields. Animals are not reared efficiently and the lack of protein in the human diet leads to severe malnutrition. If these countries are helped financially and the people are taught to farm their lands properly and to eat a balanced diet the problem of hunger should disappear. It will probably be necessary to use hitherto untried sources of protein, for the land is often unable to support large numbers of cattle. Game animals and fish will certainly gain in importance. The elimination of hunger in this way is the aim of the 'Freedom from Hunger Campaign'. The solution of the world's food problem will then include the following:

1. Conservation of the world's natural resources.
2. The organisation and farming of 'wild life'.
3. The control of pests and weeds which waste food.
4. The adjusting of environments to bring more areas into cultivation, and to increase production from existing farm land.
5. The development of new techniques for food production.

A typical daily diet in the U.S.A. compared with the daily diet of an Indian worker. The weight of food eaten by an American is nearly three times that eaten by the Indian, and the protein content is far greater. The aim of the Freedom from Hunger Campaign is to provide a sufficient and balanced diet for everyone.





Where natural controls are absent, Man must take over. Here, Conservation Corps volunteers are clearing scrub to maintain the downland habitat.

Conserving nature

To many people the expression 'nature conservation' means putting a fence around some interesting plant or animal community and keeping everyone away. This is rather like believing that atomic power can be obtained by putting uranium in a box and leaving it alone. In both cases some sort of management is necessary to get the desired results.

The balance of nature has been finely adjusted over millions of years, and every organism, be it plant or animal, depends upon another for food, shelter, etc. The removal of any one will upset the balance and affect the whole community. For example, if a fence is erected around a rare orchid on the downs many animals will be excluded. The lack of nibbling will allow trees to grow and shade the orchid. It will then perish. This state of affairs has actually been reached on some downland since rabbits were almost wiped out by disease. Trees and shrubs must be removed to maintain the open downland.

Conservation, however, means much more than the preservation of interesting species. It means conserving the whole natural resources of an area, regaining and maintaining the balance of nature that has been largely destroyed by Man's activities.

A natural habitat, where a balance has been reached, is *stable*. Dead trees and animals are replaced by nature without any change in the general surroundings. Primitive Man did not disturb this stability. As a hunter he wandered through the forests killing animals only here and there. Even the early agriculturists did not greatly upset the balance. They cleared small areas of forest and moved on when the soil was exhausted. The clearing then filled in naturally. As Man settled down to an agricultural life and his numbers increased he cleared more and more forest for growing crops and grazing his cattle. New balances were set up: with the animals preventing the growth of trees, grassland became the dominant feature.

For some centuries all was well, but as the human population increased more and more land was taken for agriculture. The wild inhabitants were concentrated into smaller areas and the balance has become truly upset. For example, elephants and hippopotami have been concentrated into small areas to such an extent that they are destroying their habitat. Animals are

Nature reserves and national parks are being set up to study conservation. With proper management they can provide the answers to many problems. They are not only sanctuaries for wild animals: they are also laboratories for ecologists – the scientists who study the relationships between plants and animals and their surroundings. In these reserves they can study the effects of tree-felling, of grazing etc. They can decide how many animals a given area can support and how best the land can be used. Nature reserves, in fact, will probably show Man how he can regain the balance of nature and overcome his greatest problem – hunger.

If there are too many animals in an area they will eat all the available food. Plant life may be destroyed and the region becomes barren. Controlled cropping will prevent this.

having to be shot in order to conserve their surroundings and the animal species themselves. There is, of course, strict control over the shooting. It is necessary to restrict numbers to the maximum that the region can support.

Another example of the upsetting of the balance of nature occurs where cattle have displaced native grazing animals such as antelope. The native animals are usually the most efficient in their own surroundings and make the best use of resources. Cattle could not make such good use of the land. Overgrazing resulted and soil erosion followed. The balance of nature could have been maintained by retaining the native animals and 'cropping' them periodically. This involves shooting some animals to maintain the most suitable numbers. If numbers become too large the habitat may be destroyed and the animals will suffer. If numbers are too small they will not survive. It is only by such controlled 'cropping' of natural resources that Man can hope to produce sufficient food.

Game ranching

A healthy diet demands an adequate supply of proteins, carbohydrates, fats and vitamins. *Undernutrition* results if not enough food is consumed each day. *Malnutrition* results if an unbalanced diet is eaten regularly. Diets over large parts of Africa and Asia are very unbalanced – containing only some 10 grams of animal protein daily. A typical North American diet includes about 60 grams of animal protein each day.

Although, in the under-developed countries, cereals and pulses (beans, etc.) provide a certain amount of protein, there is still a considerable deficit of this major food material. *Kwashiorkor* – a disease caused by protein deficiency – is common throughout the under-developed countries of Africa, Asia and South America. The affected people – mainly children – become very thin and develop body sores and painful swellings. A small glass of milk taken daily can put things right by providing the extra protein required, but many millions of people do not get even this.

Why is there this deficiency of protein? In many cases – in India, for example – there are religious restrictions on eating animal flesh or animal products. In Africa the soils are often so poor that they cannot support good grazing land. Cattle are therefore skinny and provide little nourishment. What cattle there are are often kept as status symbols rather than as a source of food. The people subsist on a diet of cereals with a very low protein content.

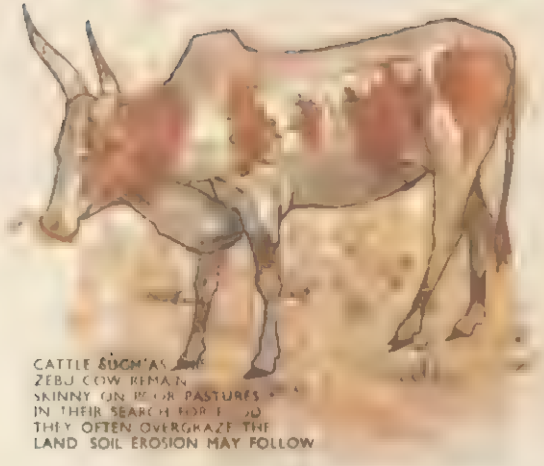
Where, then, is the much-needed protein coming from? Many scientists favour game ranching, especially in Africa.

Despite the poor soils found over a large part of the African continent, the region supports vast herds of antelope and other game. These animals have evolved with the flora of the continent and are far more efficient at converting the plant food into meat than are the introduced cattle. Each species usually has a favourite food plant – some graze one type of grass, some another, while further species may browse on shrubs. This varied feeding means that a given area can support many more wild animals than it could domestic cattle. Cattle tend to graze only one type of grass and continue to graze until it is no more. African soils can rarely support the lush pastures necessary to maintain herds of cattle. Soil erosion then begins and the whole region deteriorates. The more efficient natural inhabitants do not overgraze the land. Moreover, the natural animals are to some extent immune to many of the local diseases. Their general health is always better than that of introduced animals.

What possibility is there of using these wild animals for food? Work carried out on various African ranches shows that a given region gives a larger financial return from game than from cattle. The meat is acceptable to most of the population and if marketing arrangements are worked out there is no reason why game ranching should not provide a good deal of the world's much-needed protein.

In Africa there are many game animals that could be used with advantage. Zebra, wildebeest, impala, eland, elephant and waterbuck are only a few. The saiga antelope is used in the same way in Russia, and for centuries various Siberian peoples have kept semi-domesticated herds of reindeer.

A lot of preliminary work is necessary before game



The soils in Africa rarely provide the lush pastures needed for cattle. Where they are good enough, the disease-carrying tsetse fly often closes the land.

The Saiga Antelope of Northern Europe and Asia is already used for food on a large scale. More than 100,000 animals are killed each year without harming the species as a whole.

ranching can be undertaken on a large scale. Indiscriminate shooting would soon exterminate the game and provide only a temporary supply of meat. The aim of game ranching is to *conserve* the species in their natural habitat and to kill only that number that will maintain a steady population at equilibrium with the surroundings. The number to be killed annually depends upon the size of the population, the birthrate, the ratio of the sexes and several other things.

The biology of the animals must be thoroughly studied to find out the age at which they start to breed and the number of offspring produced at each time. Feeding habits will give ecologists some idea of the numbers that a region can support. Rough surveys each year will show the approximate number of animals that can be removed without harming the population. As a rule, the young males are the main target of the hunters, but enough must be left to ensure a constant supply of adult males each year.

Apart from the greater amount of meat provided by game as opposed to domestic cattle, the cost of keeping game is far less. Extra fencing may be necessary, but maintenance of good pasture ceases to be a problem when game is kept. There is also no need to protect the wild animals against disease: they have a natural immunity to most of the local pests and diseases.

Game ranching is a way of fulfilling two needs at once. It will provide the much-needed protein – especially in Africa – and it will help to conserve wild life. Hitherto, indiscriminate shooting has endangered many species and upset the balance of nature. There has also been the threat of soil erosion by keeping too

Zebra, Impala and Eland, three of the many African animals that could be used for food. Detailed surveys by biologists will be necessary to find out how many animals can safely be killed each year.

many cattle. The soil fertility and the balance of nature *must* be maintained if Man is going to get the most from the land.

Food from other animals

Game animals are by no means the only ones which might be used for food in years to come. Fish will be exploited far more than at present, so let us look at this possible source of food.

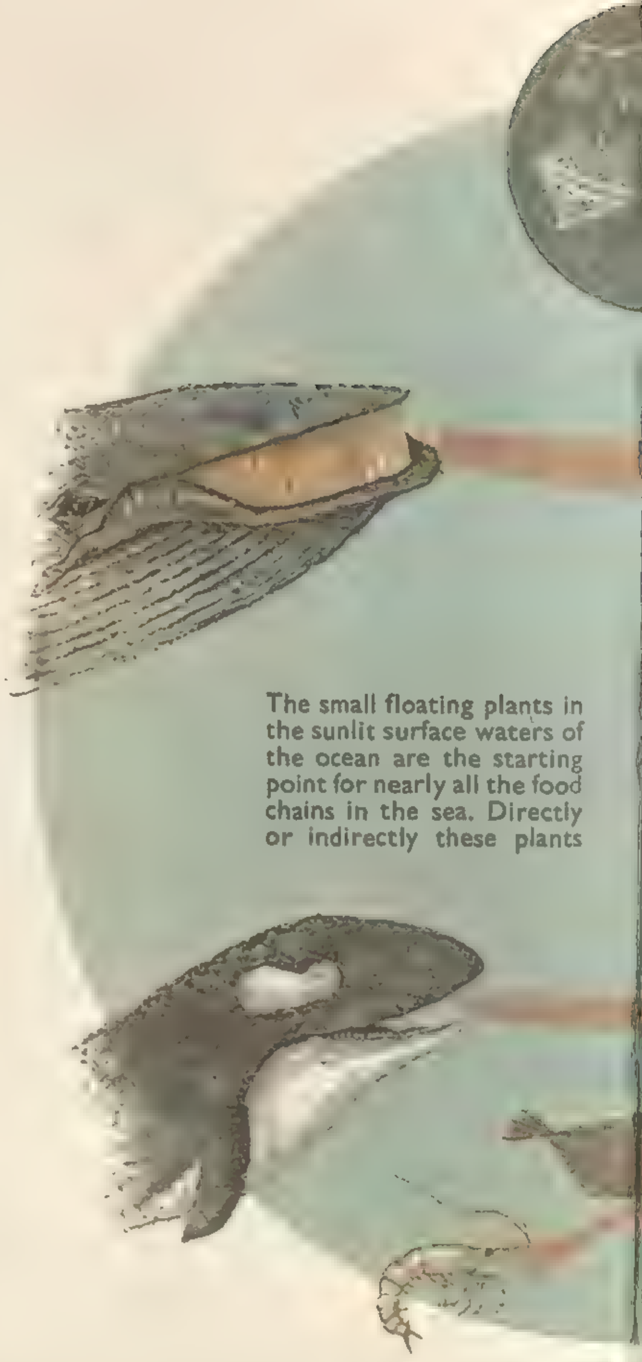
Farming the seas

Until a few thousand years ago Man was merely a hunter on the Earth. Not until the Neolithic revolution (about 7,000 years ago) did he begin to settle down to agriculture. By tending the soil Man was able to increase his food supply without roaming over large areas in search of it. As far as the seas are concerned, he is still almost entirely a hunter. He catches fish and other animals but does little to encourage their growth and continued supply. Apart from piping sewage into off-shore waters, Man does nothing but take from the seas.

Although the resources of the seas are enormous, they are not inexhaustible – some fishing-grounds are already seriously over-fished. The increasing need for food – especially protein food – in the world today will make even greater demands upon the sea, and it is unlikely that these will be met without some sort of management or 'farming of the seas'. The fisherman must change his outlook from that of hunter to farmer. Oysters and other shellfish have been cultivated for centuries, but fish in the sea present more of a problem. They are mobile and are not confined to territorial waters. International co-operation will be necessary to make a success of sea-farming.

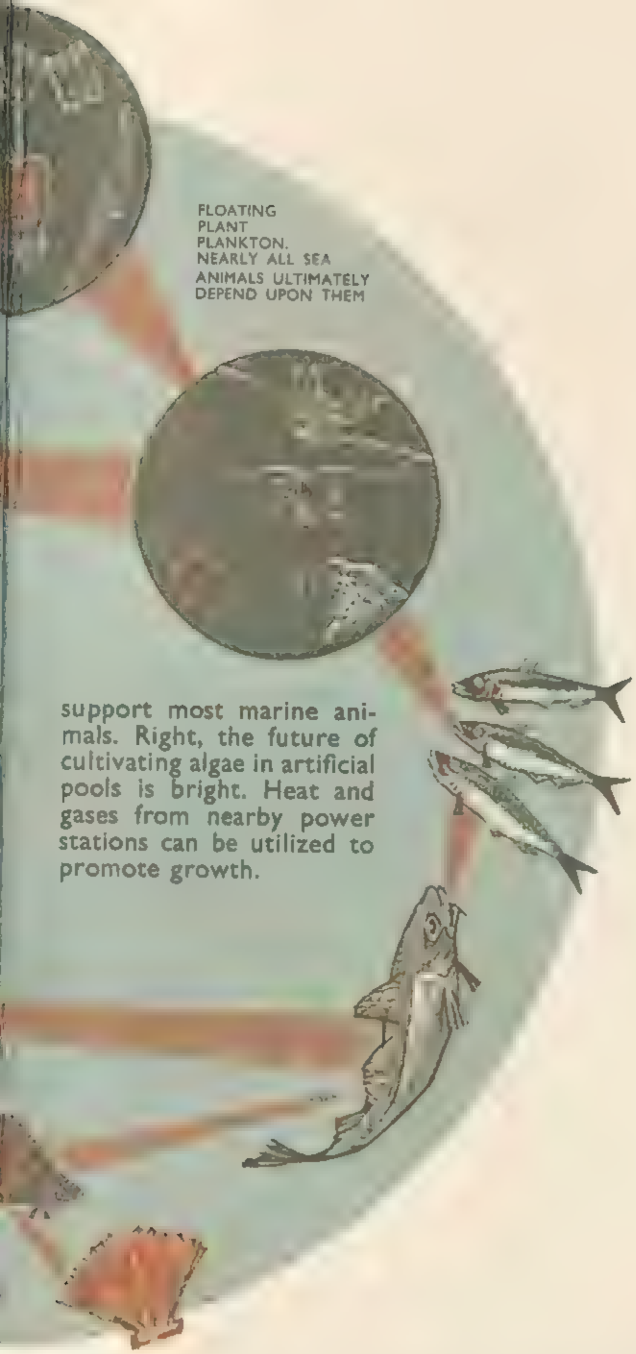
All life in the seas depends upon the minute single-celled plants of the plankton. These tiny organisms float in the surface layers of the ocean where there is adequate light. The individual organisms are microscopic but they are so numerous that their total mass would outweigh the vegetation of the land. Tiny planktonic animals such as crab larvae and shrimps feed on the plants, and these form the food of small fishes such as herrings. Larger fish feed on the smaller fish and so make up the food chains in the sea.

Many of the planktonic organisms die without being eaten. These dead creatures, together with the excrement of others, fall towards the sea-bed where they are consumed by a host of bottom-living animals – worms and molluscs especially. The bottom-living creatures are preyed upon by starfishes, sea-urchins and numerous fish.



The small floating plants in the sunlit surface waters of the ocean are the starting point for nearly all the food chains in the sea. Directly or indirectly these plants

The planktonic plants on which all the other organisms depend, themselves depend upon an adequate supply of mineral salts. If these are lacking, the size and number of animals will fall. This is well shown in tropical regions where the warm surface layers are not mixed with the deeper layers. The population of plankton and other animals is rarely as high as in colder regions, for the surface layers lack the vital minerals. All the major fishing grounds are in colder regions, where sinking cold water forces up the

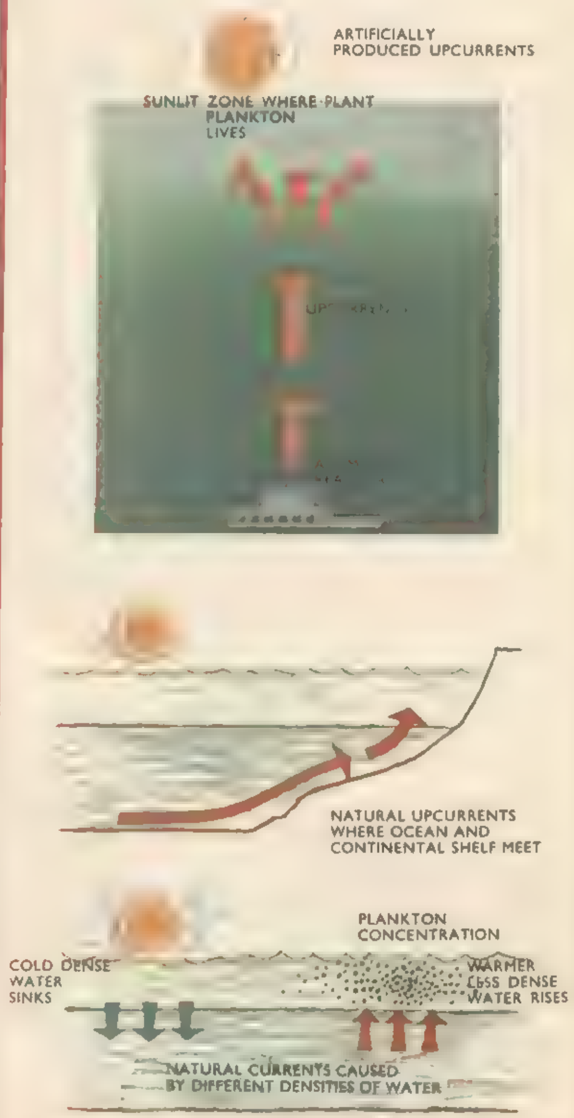


support most marine animals. Right, the future of cultivating algae in artificial pools is bright. Heat and gases from nearby power stations can be utilized to promote growth.

richer water from below, or where submerged banks produce upward currents from the depths. Plankton and all other organisms flourish in such places because of the upwelling of minerals. There is a definite tendency for fish to be larger off the mouth of the Thames – associated with the sewage brought down.

Trials have been carried out in some areas with fertilizers added to the sea, just as is done on the land, and in fish ponds. Promising results were obtained in terms of increased growth of fish, but this method would be used only in restricted areas where currents would not disperse the minerals too widely. Another suggested method is to set up a number of nuclear-powered pumps on the sea-bed. These would produce up-currents of rich water and promote greater productivity.

Plant plankton in surface waters depends upon mineral salts brought up from the depths. A possible way of supplementing the natural up-currents is to install atomic reactors at selected places. The warm water about the reactor, having less density, would rise.



These methods of increasing the mineral salts favour the growth of all organisms, not only the fish. For a given addition of fertilizer the yield in terms of extra fish will be low, for there is much competition for food in the sea, especially on the sea-bed. The elimination of some of the competitors may well be an important feature of sea-farming in future. Already starfish are methodically removed from oyster beds with good results and used for animal food or fertilizer.

Food from algae

On its way through the various links in the sea's food chains much of the nutrient material is lost in the formation of skeletons and other inedible parts. This loss can be avoided by harvesting at an earlier stage in the food chain, and a great deal of research is being directed to this end.

Various fresh-water algae have been tested by human volunteers as an addition to diet. The algae (*Chlorella* and *Scenedesmus* in particular) have a high protein content but are not very digestible. Amounts in excess of about 100 grams per day produce vomiting. Up to this amount was tolerated if well mixed with other foods. If some method of improving digestibility and flavour is found, algae (both fresh-water and marine) will no doubt play a part in the economy of countries where there is a deficiency of protein.

The culture of algae is some way ahead of developments in processing. Both fresh-water and marine forms are widely cultured in large tanks. Nitro-genous and phosphatic fertilizers are added to encourage growth, and sometimes flue gases from power-stations are pumped through the water. These increase the carbon dioxide content of the water and therefore promote extra growth. Waste heat can also be used to promote growth.

Harvesting poses some problems. The minute cells have to be efficiently removed from the water and then rapidly dried or frozen. Freeze-drying is possibly the best method but it is expensive. These difficulties, added to the fact that algae are not, at present, very acceptable for food, make indirect harvesting more attractive. There are a large number of animals – especially bivalve molluscs – that feed by filtering tiny particles from the water. It may well be that the culture of algae will be linked with the increased culture of shellfish. The latter would provide an easily harvested and rich source of acceptable protein.

Culturing fish in ponds and lakes

Fish culture in ponds is no new thing. The ancient Egyptians certainly cultured *Tilapia* (a lake-fish) about 4,000 years ago. The Chinese and other Asian peoples have also cultured fish for centuries – carp and *Tilapia* especially. Large lakes created by hydro-electric schemes may be ideal places for fish culture, as are the large natural lakes of East Africa. The principle is the same as that for the culture of marine fish – the addition of fertilizers to promote growth of plant food. Many of the disadvantages of marine fish culture are absent in lakes, however – the fish are relatively confined, and the lakes can be stocked with useful, quick-growing species. *Tilapia esculenta* and *T. variabilis* are playing an important part in fresh-water research in East Africa and should add considerably to the protein production of the continent.

A method of growing algae using industrial by-products.

5. The Control of Pests and Weeds

The Control of Pests and Weeds

A GREAT deal of the world's food production is lost or contaminated each year by the presence of either weeds or pests or both. It has been estimated that crop yields in Britain are reduced by over £60 million annually because of weeds, and in the U.S.A. a recent official estimate has put the combined losses caused directly by weeds and the measures taken to control them at nearly $4,000 million.

Let us look first at weeds and how they can be controlled, then at a particular pest, the locust, and finally at a method of 'natural' control.

The natural history of weeds and their control

A group of poppies growing naturally on a hillside may be an attractive and welcome sight, but in a field of wheat these same flowers would be called harmful *weeds*. We can say, therefore, that a weed is a plant growing out of place or where it is not wanted. Weeds occur on waste land, roadsides and all disturbed ground, but it is in cultivated fields that they are most obvious and most important. There they compete with the cultivated plants for water and mineral salts and also for light. Recent investigations suggest that some weeds even produce in their roots substances which reduce the growth of other plants. Apart from this direct competition with cultivated plants, weeds may harbour numerous pests and diseases which can spread to the crop and cause much damage.

Weeds are characterised by their high seed production and their ability to colonise disturbed areas quickly and to compete effectively with other plants. Indeed, without these features a plant would not become established as a weed. There are two main types of weed in cultivated land: small, quick-growing plants, often with several generations per year, and perennial herbs (e.g. bindweeds) with creeping rootstocks which continue to produce new plants even when broken into small pieces. Both of these forms can survive cultivation processes and produce a fresh crop of weeds each season.

Weeds can harm cultivated crops in a variety of ways. The aerial parts compete for light, while underground the roots compete for mineral salts and water. Such competition is often particularly damaging when crops become infested at an early stage of growth. Some weeds are poisonous to livestock and others may taint milk when eaten by cattle. Weeds can act as reservoirs of pests and diseases which may spread to crops. In non-agricultural situations, too, weeds may be a serious nuisance; for example, on railways, rights-of-way, industrial sites and the like.

Ever since man began to till the soil he has had to take steps to control the weeds which sprang up to choke his crops. Present-day ways of controlling weeds may be either *cultural* or *chemical* in nature. Cultural methods were until recently the only methods the farmer could use, and it is therefore appropriate to discuss them first.

In early times, and, indeed, until comparatively recent times, hand-pulling and hoeing were virtually the only ways available for killing weeds. These methods could only be used on a small scale and it was not until it became usual to sow crops in rows instead of broadcasting them that further progress could be

Poppies, thistles and mayweed all compete with the wheat for water and dissolved salts. The taller weeds produce much of the impurity in the harvested crop.

The dandelion's tough tap root withstands a certain amount of disturbance. The chickweed (right) survives as a species because of its rapid growth and seed production.

made. In the 18th century Jethro Tull, an Englishman, developed a horse-hoe which could be used to till between crops sown in rows. Since his time the tractor has taken over from the horse and the techniques of weeding between rows have been greatly refined and improved. Such methods, however, can be used only in crops sown in wide rows, such as sugar-beet, kale and some vegetables. Weeds between plants in the row have still to be removed by hand. Cereals are sown in rows too narrow to permit effective row tillage; and until chemical methods of controlling weeds were recently introduced, weeds were always a serious problem in these crops.

An important measure to reduce weed infestations in cereals was the very simple one of using only 'clean' seed (i.e. without weed seeds). Before the importance of clean seed was recognised, great quantities of weed seeds were commonly sown along with the crop seed, and this helped to maintain high weed populations and to spread weeds into areas where they did not already occur. Most countries now have laws which make it illegal to market seed contaminated with more than certain amounts of weed seed.

The most striking advances in weed control, however, have been made by the discovery of chemicals which have the ability to destroy weeds and yet leave the crop intact. Certain chemicals, such as sulphuric acid and copper sulphate, have long been known to have *herbicidal* (plant-killing) properties under certain circumstances. It was not, however, until the discovery of the so-called *plant growth regulating compounds* in the 1940's that the real breakthrough came.

These compounds are closely related to certain growth hormones which occur naturally in plants and which assist in regulating their growth. When applied in large enough amounts to the leaves, they enter and move in the sap to different parts of the plants, where they upset the natural processes of life, disrupt growth and eventually cause death.

Examples of these compounds are the chlorinated phenoxyacetic acids, of which the most commonly used today are *MCPA* (4-chloro-2-methyl-phenoxyacetic acid) and 2, 4-*D* (2, 4-dichlorophenoxyacetic acid). These herbicides have the extremely important property of being *selective*. In this case, they are active against broad-leaved plants, but not against members of the grass family (such as the cereals). This means in practice that these compounds can be used to control many annual broad-leaved weeds in cereal crops and lawns. *MCPA* and 2, 4-*D* are today used on a world-

Spraying potato tops with dilute sulphuric acid kills the tops so that lifting the crop is made easier.

The principle of selective action of sulphuric acid is that the cereal crop throws off the spray droplets while the weed leaves get covered and killed off.

wide scale and their total contribution to increased crop yields has been enormous.

Since these compounds were developed, many others, some with very different modes of action, have been discovered.

The first group of these includes the so-called *contact herbicides*. We have already mentioned sulphuric acid; other examples are the dinitro compounds *DNOC* (3, 5-dinitro *ortho* cresol) and *dinoseb* (2, 4-dinitro-6-*sec*-butylphenol), and the new bipyridyl herbicides *diquat* (1, 1′-ethylene-2, 2′-bipyridylium) and *paraquat* (1, 1-dimethyl-4, 4′-bipyridylium). All these compounds kill those parts of the plant with which they come in contact and act very rapidly. They do not move through the sap into other parts of the plant. The dinitro compounds are effective against weeds in cereal crops and in peas and lucerne. They are, however, very poisonous and their use is declining. The use of diquat, and especially paraquat, is increasing. They are comparatively non-poisonous and have the useful property of being broken down rapidly in the soil.

The next group of herbicides includes those which are commonly applied to the leaves and which are then *translocated* through the plant in its sap. *MCPA* and 2, 4-*D* have already been mentioned. Other examples are the phenoxybutyric and phenoxypropionic compounds, which are effective against certain broad-leaved weeds: *dalapon* (2, 2-dichloropropionic acid) and *TCA* (trichloroacetic acid), which are active against grasses, and *amino triazole*, which is active against most plants.

The translocated herbicides are rather slow in action and for this reason are not used for *pre-emergence* application (i.e. against weeds appearing between sowing and emergence of the crop).

The last group of herbicides includes the *soil-acting herbicides*. This group is of increasing importance and includes many compounds. In general they are extremely insoluble and act through the roots rather than the leaves of plants. They are usually applied to bare soil, enter weed seedlings through the roots and kill them when they emerge from the soil surface. Examples

Aquatic Weeds

The Canadian Pond Weed (*Elodea canadensis*) became a nuisance some years ago in British waters and, more recently, the Water Hyacinth (*Eichhornia crassipes*) has been giving trouble in Africa. This plant has covered vast stretches of tropical rivers and large sums of money are being spent on its control. The plant exists as floating masses which may or may not be attached to the banks. The leaves stand clear of the water. Broken pieces rapidly grow into new plants and the infestation spreads, both naturally and by man's intervention.

Navigation is almost impossible on some of the more affected rivers. Fishing suffers and animals are unable to drink freely. As the leaves are above the surface, spraying with herbicides such as 2, 4-*D* is possible and effective. Completely submerged weeds are best controlled by mechanical cutting and dredging. Chemical treatment of rivers must not harm the fish or other animal life, nor must it endanger the drinking supply taken from the river lower down its course.

are the triazine family of herbicides, the phenylure and the phenyl carbamate families.

Total weed control

On non-agricultural land such compounds as sodium chlorate, borates, the phenylureas and simazine, used in large quantities, will kill existing vegetation and also persist for a long time, perhaps for up to two or more years, in the soil. This provides a way of keeping railway tracks, fence lines, driveways, etc., free from vegetation for a long time.

The locust problem

Many insects form swarms, but none travels so extensively or inflict so much damage on crops as locusts. A swarm may be so large and so dense that the sky is blackened. It may contain several thousand million locusts with a total weight of perhaps twenty thousand tons. Each locust is able to consume its own weight in food per day, and so vast areas are quickly stripped of natural vegetation and crops. But swarms can move almost a hundred miles in a day, so that the damage is not restricted solely to one area. A swarm that ends up in Morocco may have come from the equatorial parts of Africa more than two thousand miles away. Thus a trail of destruction is left behind. Moreover, during such a migration individuals may breed again within a year of their birth. A female locust may lay three hundred eggs during her lifetime, and so, as the swarm moves on, a vast potential population is left behind.

Of greatest economic importance in the Old World are the migratory locust (*Locusta migratoria*), the desert locust (*Schistocerca gregaria*), the red locust (*Nomadacris septemfasciata*) and the moroccan locust (*Dociostaurus maroccanus*). In the New World the South American locust (*Schistocerca paranensis*) is most important.

The migratory locust is the most widely distributed, affecting almost the whole of Africa, southern Asia, the East Indies, part of Australia, and New Zealand. The desert locust inhabits the northern half and much of East Africa, the Middle East including Arabia, Israel, Syria, Iraq, Jordan and Persia, and the whole of India.

For a long time the sudden appearance of plagues of locusts followed by their disappearance was a complete mystery. In the 1920's, however, Dr. B. P. Uvarov of the Anti-locust Research Centre put forward the suggestion that each species of locust existed in two phases, a *solitary* phase and a *gregarious* phase. These differ so markedly that they had been considered as

Locusts for research are reared in special cages in a controlled temperature room.

separate species. The solitary forms live in low-density populations. They are usually green and have no constant colour patterns. But the gregarious forms live in *swarms* (as adults) or *hopper bands* (as young stages). They are more active, feed ravenously and show a striking constant pattern of yellowy-orange and black. The apparent disappearance of the locust swarms is due to the disbandment of the swarming phase. The species continues to exist as the more thinly spread solitary phase.

Swarming is thought to occur mainly when a period of favourable conditions, permitting a big increase in the numbers of solitary individuals, is followed by poor conditions (e.g. drought). This drives the locusts to seek out the small quantities of vegetation that remain. They are thus brought together and the impetus to swarm is provided.

Further research has shown that, in the case of the red and the migratory locusts, there are certain *outbreak areas* – regions where swarming is most likely to

A vehicle equipped for spreading insecticide over the desert.

occur. Careful watch on those areas has meant that outbreaks can be stifled in their early stages. The desert locust is more of a problem, however. Its outbreaks are scattered and irregular, and it is probable that small swarms, at any rate, are always in existence.

The locust is just one example of an animal pest which is capable of destroying very large amounts of foodstuffs. At the moment it is being controlled by the use of insecticides, but it has been discovered that many insects gradually become immune to insecticides, and that indiscriminate spraying also kills useful insects, so what other methods of controlling pests and weeds are available?

One method which requires a great deal of ecological research is called *natural* or *biological control.*

Biological control

Perhaps the first really successful use of biological control was in the almost complete extermination of the fluted scale insect, a bug which caused great damage to the orange trees in the Californian citrus groves. This pest first appeared there in 1868, having been accidentally introduced from Australia on imported acacias. Its numbers quickly reached pest proportions. C. V. Riley made a careful study of the insect. He found that in its native land it was held in check by its

Apart from the fact that outbreaks are widely scattered, often unpredictable, and of such gigantic proportions, the very geography of the countries that they inhabit makes the control of locusts an immensely difficult problem. Much of it is desert or semi-desert, without roads, water or other amenities.

The main control method used at present is one of applying poisoned bait against the young stages. Insecticide, such as gamma BHC, dieldrin, or aldrin, is mixed with a bran or similar base and spread in front of and amongst the marching hoppers. Wide areas are not easy to cover, however, because of difficult terrain, the large quantities of bait needed (only about 0·1 per cent of the bait is active insecticide) and the enormous labour force required to spread it. The method is ideal for controlling small hopper bands, but is not sufficiently mobile to cope with larger, unexpected plagues.

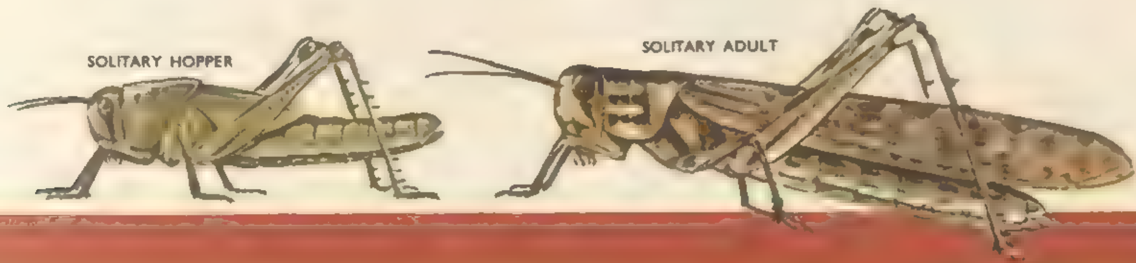
More concentrated insecticides have been applied to the vegetation on which the hoppers feed. Less bulk of insecticide has to be carried, and so the expense is considerably reduced. Dieldrin is a suitable insecticide and retains its potency for almost a month. The exhaust of a vehicle, such as a Land Rover, has been adopted to disperse a fine spray of dieldrin downwind. In a day a single operator can apply the same quantity of insecticide as can a thousand labourers.

natural enemies. Its activities never reached pest proportions. Several of the insect's enemies were sent to the United States of America and in a series of carefully controlled experiments the larvae of a species of ladybird successfully cleared a test tree of the pest. The predatory beetles rapidly increased in numbers, spreading over the orange groves. Within a few years from the time of their introduction in 1889 the pest was brought under control and the industry was saved from impending disaster. Today the fluted scale insect is no longer a major pest in the U.S.A., but a stock of ladybirds is maintained so that any local outbreaks of the pest can quickly be controlled. To date, such measures have always been successful.

This particular example of the application of biological control is a near perfect one. Almost the first of the pest's enemies to be experimented with proved successful as a means of control and there have been no side effects, such as the beetles themselves becoming pests.

The Ladybird, Rodolia cardinalis, *has successfully controlled the Fluted scale insect,* Icerya purchasi, *a pest of orange trees in California. Adults and larvae are predators.*

Before discussing further successful examples it is as well to consider the problems of the scientist in looking for the most suitable natural enemy of a particular pest.



It is hoped that successive hopper populations will feed on the sprayed vegetation, thus increasing the effectiveness of the control. Further information is required on the distribution of hopper populations before the method will achieve maximum efficiency. Quicker distribution of insecticide will probably be possible from the air.

Other methods of control are directed against the locust swarms. Locusts swarm for the greater part of their life and it is then that they cause most damage. In some areas, such as those bordering the Red Sea, the swarms remain in one place long enough for poisoned bait to be used effectively. Generally though, the swarms are so mobile that aircraft have to be used both for reconaissance and spraying.

The flying swarms are most dense in the late afternoon and evening. This is the time when spraying is most effective, for any that misses the swarm will often land on vegetation that the locusts will feed on later. Gamma BHC, dieldrin or diazinon are the insecticides used. Many thousands of gallons may be needed if the invasion is a large one.

The spraying of large areas with insecticides has its problems, however. Many beneficial insects may be killed, besides the locusts. Generally though, locusts are attacked by spraying in areas away from the crops that they threaten. The threat to crop-pollinating insects is only slight, therefore.

Many insects parasitize others. This Sphinx moth caterpillar is covered with the cocoons of a parasitic wasp.

There are many examples of a control having been introduced without proper care. A plague of caterpillars in parts of New York was stripping the trees of their leaves. The introduction of sparrows from Europe removed the caterpillars. But sparrows are also seed-eaters competing with others for food and very soon had themselves become pests, driving many of the American birds from their natural homes.

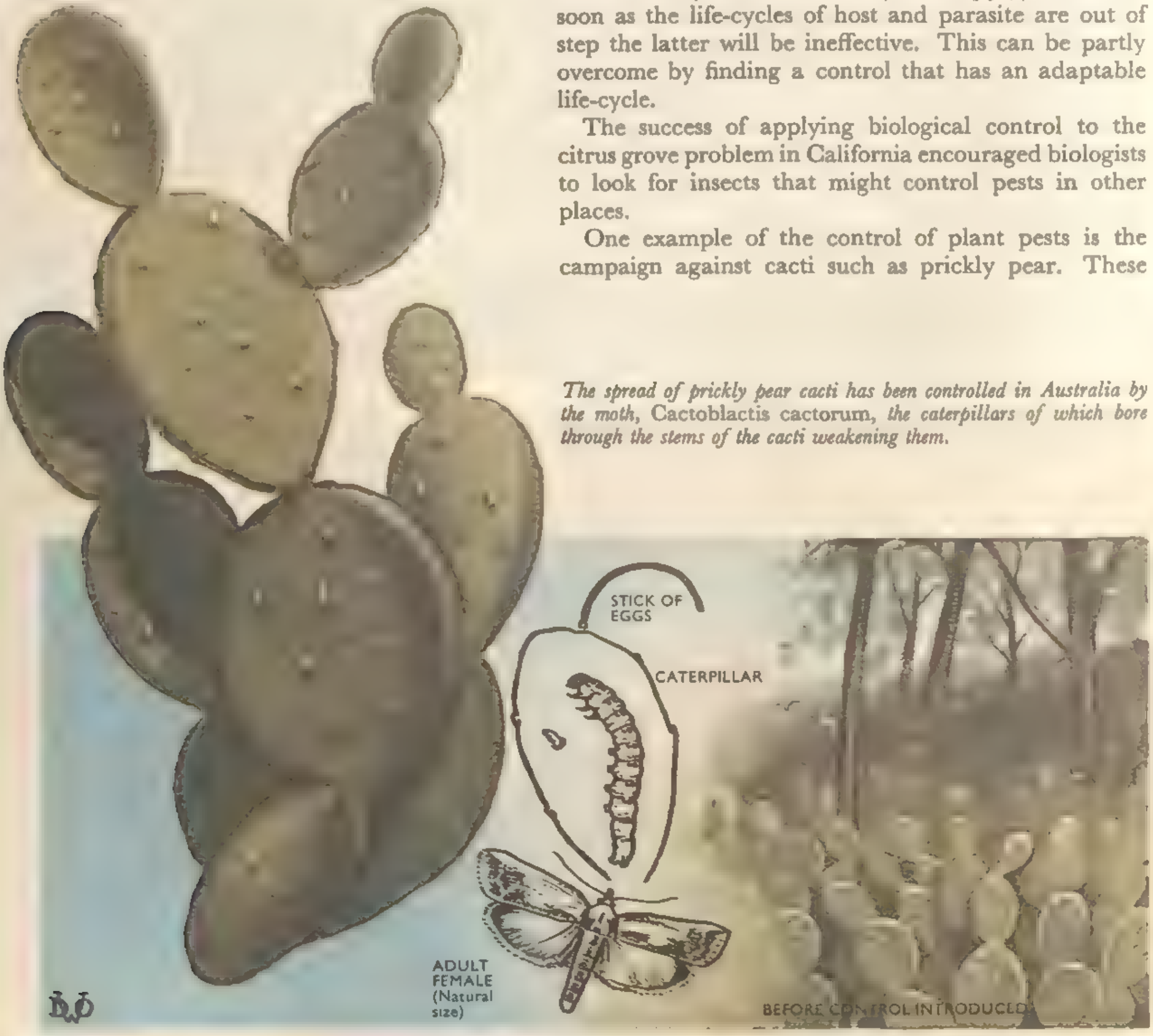
Will the control itself become a pest? The possibility of this happening is very real, and so the life history and the habits of the proposed control factor must be thoroughly worked out.

Another factor of considerable importance in limiting the application of biological control is climate. If the control is introduced into a warmer country its life-cycle may not be speeded up to the same extent as that of the host (the converse may also apply). Thus as soon as the life-cycles of host and parasite are out of step the latter will be ineffective. This can be partly overcome by finding a control that has an adaptable life-cycle.

The success of applying biological control to the citrus grove problem in California encouraged biologists to look for insects that might control pests in other places.

One example of the control of plant pests is the campaign against cacti such as prickly pear. These

The spread of prickly pear cacti has been controlled in Australia by the moth, Cactoblactis cactorum, *the caterpillars of which bore through the stems of the cacti weakening them.*



grow naturally in North and South America but were introduced into Australia as ornamental garden plants. By about 1925 these cacti had spread to such an extent that they covered over 90,000 square miles – equal to the area of Great Britain.

A large number of insects that live on cacti were experimented with in an attempt to bring the cacti under control. Eventually a moth-borer, *Cactoblactis cactorum*, native to Argentina, was thought to be suitable. It was released in Australia and very quickly the larvae destroyed large numbers of the plants by boring into and weakening them. This not only stopped it spreading further but actually reduced the area infected.

This example also illustrates how complicated are the relationships between the animals and plants of a community and what great problems exist in choosing a suitable controlling agent. In South Africa the introduction of *Cactoblactis* to cure a similar problem was nothing like so successful.

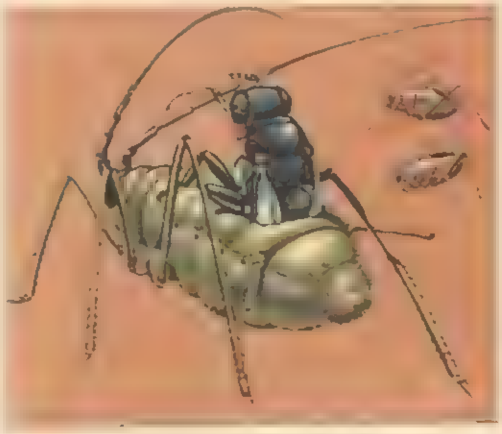
In Britain biological control has had limited success. The white-fly, a common pest of tomato plants in greenhouses, has been controlled to some extent by a minute chalcid – *Encarsia formosa.*

Reports from Italy suggest that a tiny chalcid, *Prospaltella berlesei*, has brought the mulberry scale, *Diaspis pentagona*, under control and thus has saved the silk industry in Italy.

The Cucumber Beetle is attacked by a species of roundworm. Experiments indicate that the latter may effectively control the beetle.

Several species of fishes have been used in the tropics (guppies are illustrated) to help control the spread of malaria. They consume the larvae and pupae of the malaria-parasite-carrying adult mosquitoes.

Many insects are natural parasites of others. The illustration shows the adult of a chalcid emerging from an aphid nymph.



There are records of devastating effects of plagues of locusts in very early writings. Control is largely by chemical means but a parasitic fungus gives a certain degree of natural control. Several locusts are shown dying from a fungal attack.

It is very difficult to evaluate the success of biological control in specific examples. Even when a pest's numbers are controlled or reduced it is possible that other natural factors have had some effect. However, the evidence is such that it has proved its usefulness in a number of cases and it may play an important part in the control of pests in conjunction with other methods of control (e.g. pesticides).

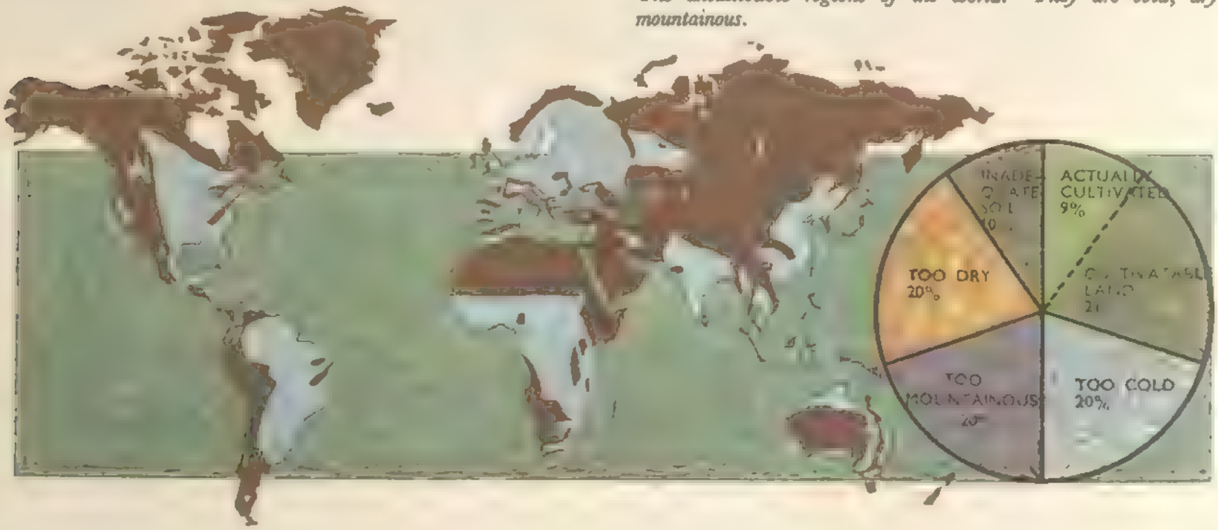
6. Adjusting the Environment

Adjusting the Environment

As has been mentioned before, much of the land of the world is, at present, unsuitable for cultivation, being too mountainous, too cold, too dry, or too wet. Little can be done to land which is too mountainous or too cold, but that which is either too dry or too wet can certainly be used if enough financial help is available.

until it reaches an impermeable rock (i.e. one which prevents penetration of water). Clays will not let water pass through them. As the water cannot penetrate any more, it builds up gradually and forces air out of the soil spaces. This water is called ground water and its surface is called the water table. If the impermeable

The uncultivable regions of the world. They are cold, dry, or mountainous.

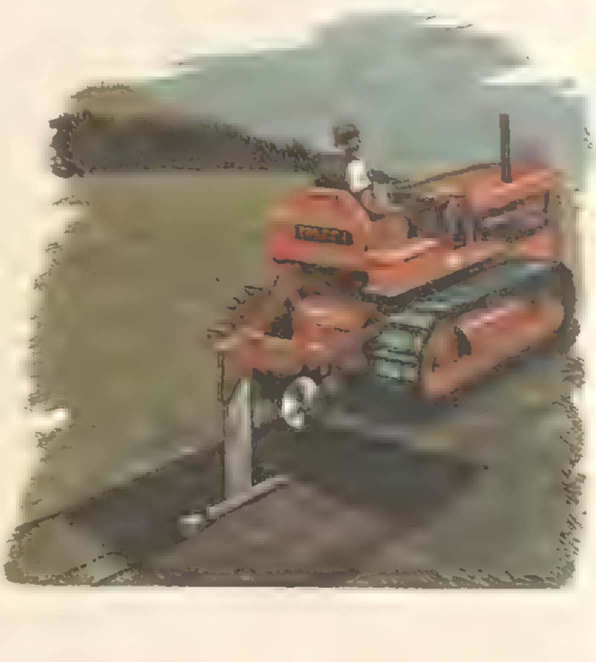


Land drainage

Low-lying areas and hollows, especially along river valleys, are frequently flooded after only a moderate rainfall. The fields (*water-meadows*), even when they are not covered with water, do not support much more than grass and such marsh-loving plants as rushes and kingcups (*Marsh Marigolds*). This is because the soil is waterlogged, i.e. the spaces between the soil particles are filled with water instead of air. Plant roots need oxygen in order to grow and ordinary plants cannot survive in waterlogged soil. The typical marsh plants have in their roots a system of passages and spongy tissue which enables oxygen to reach all parts of the root

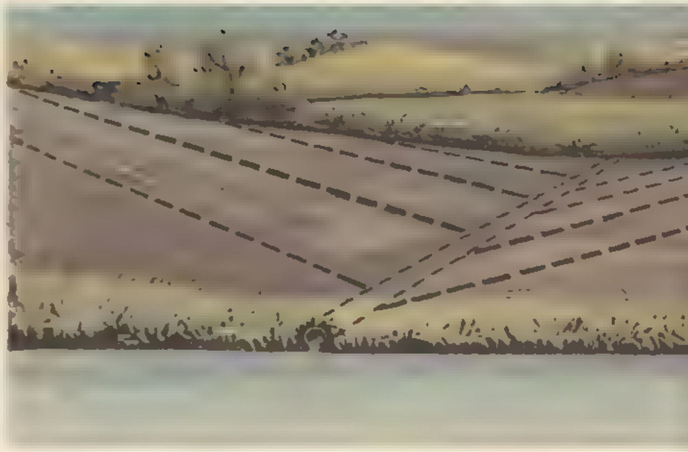
Waterlogging is the result of certain conditions in the underlying rocks, although low-lying regions may be temporarily flooded by water running off from the surrounding hills after heavy rains. When rain falls on to dry soil it is rapidly soaked up, the water being held on the surface of the soil particles. Further rain is soaked up until the soil particles are completely covered with a film of water. Any more water runs down through the soil under the influence of gravity

A powerful tractor is required to haul the mole through the heavy soil.



rock is near to the soil surface the water table may rise above the soil and create flooding. If the land slopes, the surface water will run off and the ground water will gradually drain away through the soil layers until it reaches a stream, but low-lying flat land will not drain quickly enough to be of use to the farmer.

Since much of the soil of river valleys is rich in mineral plant foods the farmer cannot afford to let it remain as unworkable marshland. The value of draining land has been known ever since agriculture has been practised. Its purpose is to convey surface and ground water away quickly and to ensure that the water table does not rise above the lower limit of root growth. Flooding due to run-off or stream overflow may be dealt with by *open drains*. These are ditches cut through the fields in order to carry the water to a lower level and into the stream again more quickly than would occur by natural drainage. Open drainage schemes have been used on a large scale for draining the fens of England and large areas of Holland.



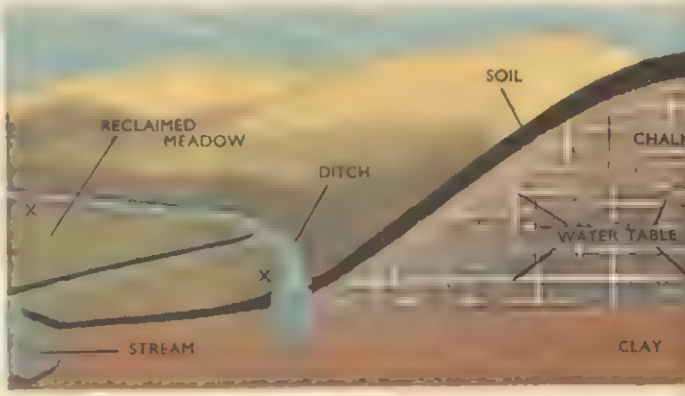
A generalised pattern of field drainage with its overflow into a small stream.

Under drainage

When agricultural land requires drainage of ground water a system of underground drains is usually employed. These may be *pipe* or *mole* drains. The pipe drains, as their name suggests, consist of a network of pipes placed at a certain depth under the surface. They are made of unglazed tile so that ground water will seep into them quite rapidly and be carried away. Thus the water table will not rise above the level of the rains. If an area is to be drained it must first be *surveyed*, i.e. the highest and lowest points must be determined together with the direction of the slopes. A plan can then be drawn up before the work is started.

The pipes must be a sufficient depth so that the normal ploughing operations will not disturb them. In light soil 3–4 feet is a very suitable depth. A heavy soil in which drainage is slow requires shallower drains – not more than 24 inches from the surface. The character of the soil determines the distance between drains too; 24 feet is a maximum in heavy soil, but drains 90 feet apart may be adequate for light soil.

Pipe drainage is very costly and is economical only where valuable, permanent crops (e.g. vines) are being grown on the land, or where other types of drainage are not practical. *Mole drainage* is such an alternative and is comparatively cheap. The minor drains are not tiled. They are channels formed by hauling a bullet-shaped piece of metal (the *mole*) about 3 inches in diameter through the subsoil. The mole is attached to an arm behind a powerful tractor. It cannot automatically allow for large surface irregularities, and is only suitable, therefore, when there is a steady fall of the land. As there are no pipes the walls of the mole drains collapse after a time and the field needs to be 'mole-ploughed' again. Mole drains are between 20 and 30 inches deep to avoid possible collapse due to the pressure of tractors or other surface disturbances. Mole drains are not so efficient as pipe drains and need to be closer together. They empty into piped main drains which are laid down in the usual way.



Water draining through the chalk is forced out at springs along the line X–X. By digging a ditch along the spring line the water can be conveyed to the stream without waterlogging the surrounding soil.

Where waterlogging is due to eruption of springs large open drains are again used. Deep channels, cut along the edge of the porous rock, convey the spring water into the nearest stream and waterlogging of the land is avoided.

Land reclamation

The term land reclamation, as well as including normal drainage work on 'damp' land, also includes the draining of land from the sea-bed, where the sea is relatively shallow, and from lake-beds and swamps.

It mainly involves drainage and protection to avoid further waterlogging, but also land that has been re-drained from the sea must be treated for the removal of salt before it can be used for agriculture. Land reclamation has been practised extensively in the Netherlands and is still actively in progress in the region of the Zuider Zee. When complete, the reclamation of this area should have added some half-million acres to the agricultural land of the Netherlands.

The Zuider Zee was first cut off from the open sea by a large dam which was completed in 1932. Dykes were then built to enclose certain areas of the enclosed lake, and pumps were set to work to remove the water. Even after the removal of the water, the pumps are still needed to keep the reclaimed land dry. Raïnwater and seepage add some 30 inches of water a year on to the reclaimed lands in Holland.

When the sea-bottom emerges it is sown with reeds and gradually reclaimed by digging ditches. As the soil dries it shrinks and cracks. Later, tile drains are laid. Chemical changes in the soil result in the removal of sodium ions and the formation of calcium clays. Leguminous crops are sometimes sown then to increase the bacterial content of the soil. Most of the area so far reclaimed is of excellent agricultural quality. Reclamation of lakes and swamps follows very much the pattern described here. There are a great many such areas in the world which would benefit mankind by being drained. Large areas of fenland in eastern England have been drained and now support some of the richest farmland in the country.

Irrigation

Irrigation (from the Latin *rigare*, meaning to water) is the artificial watering of land for the purpose of growing crops. It is usually necessary in tropical regions where the rainfall is less than 20 inches per year. Some parts of Great Britain have little more than 20 inches of rain in a year (and a few spots have less), yet crops grow without additional supplies of moisture. The difference lies partly in temperature (the great heat of the tropics means that much of the rain falling upon the land is evaporated before it can sink into the ground)

Simplified plan of the Snowy Mountains project.

Large scale irrigation by channels.

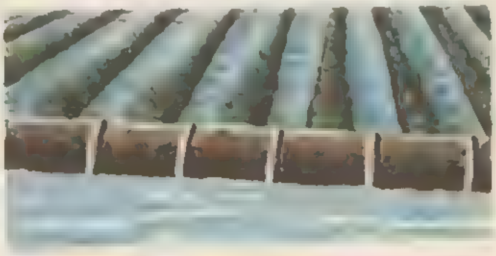
and partly in the distribution of the rainfall (a 'cloudburst' does far less good than the same amount of rain falling over several days).

In some regions irrigation may only be needed during part of the year (the hot season), whilst in other areas, such as Egypt, crops depend almost entirely upon artificially supplied water. Irrigation is also necessary where the rainfall, though sufficient, is unreliable. Great famines have occurred in such regions through farmers 'trusting to providence'. The importance of irrigation may be seen in the fact that fully half of the world's cultivated land is irrigated to a certain extent.

Irrigation may also depend upon the crop grown. Rice, for instance, which spends part of its growing period under about 6 inches of water, needs additional water where another, less thirsty plant would grow quite happily. A considerable amount of rice is grown in South-East Asia by trapping the large amounts of rainwater brought by the monsoon – hence the small, level, rimmed fields which turn whole hillsides into a gigantic flight of 'water steps'.

Irrigation in the past has been limited by the fact that it is very difficult to raise water to any great height. This is why Egypt's farmlands stretch in a winding strip through the Sahara: they are confined to the valley of the River Nile. To irrigate arid uplands is a costly business which could never be undertaken by the farmers themselves. This is also one of China's great problems. It is a vast land of fertile lowlands and arid uplands. Most of its 600 million inhabitants are farmers and most of them live in the lowlands where irrigation, if necessary, is fairly simple. As a result, many families have only half an acre of land to support them and can grow barely enough for their own needs. Thus one drought or poor harvest can spell famine to millions. Large-scale irrigation schemes have greatly eased the problem of overcrowding in India, where desert areas have been turned into fertile farmlands. Many of the world's barren lands are barren only in the sense that they lack water, and irrigation is a large part of the answer to the world's growing food problem.

The idea of irrigation is not new: in Egypt crops have always depended almost entirely upon the River Nile for water. The ancient Egyptians utilised the fact that



Furrow irrigation is the method often used to distribute water to field crops. Here water is being siphoned into the furrows.

The sprinkler system is only possible over a relatively small area, such as a market garden.

the Nile floods once per year. They developed a system of canals and ditches to carry the floodwaters through the fields – a practice which would be known today as flood irrigation. For the rest of the year they depended

upon primitive devices to raise water from the river to the level of the channels. The shadoof, a bucket on a weighted, pivoted pole, was in use in Egypt over 3,000 years ago and can still be seen serving the same purpose today; so can the Persian water-wheel, a large wheel with wooden or leather buckets attached to its rim. Archimedes' screw consists of a hollow wooden cylinder containing a spiral ledge running from end to end. When the cylinder is rotated water is drawn up through it. Sometimes animals are used to aid irrigation. Oxen may walk down a ramp to draw buckets of water up from a well. In India many villages which are some distance from a large river rely upon wells for water for their fields or have their own 'tank', a small reservoir, often with earthen walls, which stores the monsoon rains for the dry season.

Large-scale, efficient irrigation schemes can only be operated when these inundation canals (canals which fill with water only in time of flood) and other primitive devices have been replaced by perennial canals (those which carry water the whole year round) – a process that is rapidly taking place. But perennial canals are costly, for they entail the damming of rivers to control flood-waters and create artificial reservoirs which can be drawn upon at all times of the year.

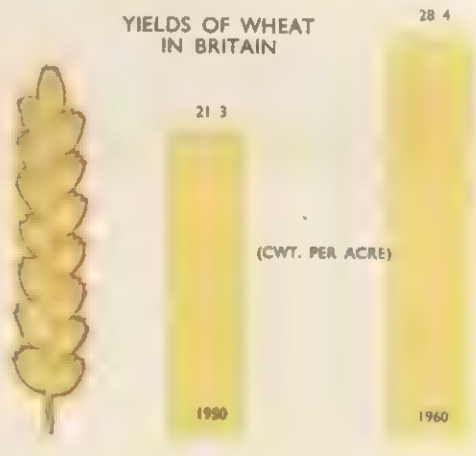
In Egypt the volume of the River Nile from August to November greatly exceeds the demands made upon it by irrigation, while for the rest of the year the natural flow cannot meet the farmers' needs. At the beginning of this century a dam was built at Aswan to control the floodwater and save some of it for the rest of the year. The dam has been raised twice since, but it still lets an enormous amount of valuable water escape to the sea. The Aswan High Dam (being built five miles upstream from the site of the old one) is the latest scheme to make full use of the river's possibilities. Behind it will form one of the world's largest artificial lakes, 1,500 square miles in extent.

The Aswan High Dam is typical of most dam projects in tropical lands. It combines flood control and the production of electricity with the storage of water for irrigation. Apart from providing water to increase the irrigated land by 30 per cent, the Aswan High Dam will eventually produce six times the amount of electricity used in the whole of Egypt at present.

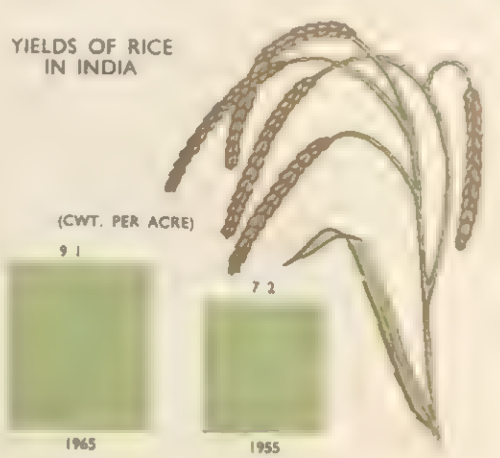
Although irrigation is often connected with Egypt, it is India and Pakistan which have the most extensive systems. In fact one great irrigation scheme, based upon the Sukkur barrage across the River Indus, changed a barren area larger than Wales and greater than the total amount of Egypt's irrigated land into fertile farmland.

One of the boldest irrigation schemes of modern times is the Snowy Mountains project in south-eastern Australia. The aim is to impound the waters of the Snowy River, which flows through a region of adequate rainfall, and lead it back *through* the mountains, largely by pipes, to augment the waters of the Murray and Murrumbidgee Rivers for the inland irrigation. The plan calls for the construction of nine big dams, more than 100 miles of aqueducts and at least ten big power stations, some of them underground.

After water has been led to a field by canal or pipe various methods are used to distribute it to the plants. Furrow irrigation is often used for field crops, the water being run along the furrows between the lines of plants. When the area to be irrigated is fairly small, as in the case of a market garden, the water may be



The way in which rice yields in India and wheat yields in Britain have been increased by the use of fertilizers.



sprayed over the plants, just as the sprinklers are sometimes used in Britain for lawns during a dry summer spell.

Increasing and maintaining land fertility

When an area of land is cultivated continuously year after year it is only to be expected that sooner or later it will become exhausted of its supply of mineral salts which are essential for the healthy growth of plants.

Many areas of land are naturally short of mineral salts, so in both cases, in order to make the land constantly useful, salts must be added.

Three main methods exist of adding mineral salts to the soil:

1. Fertilizing.
2. Composting (and manuring).
3. Ploughing-in leguminous crops.

1. Fertilizing

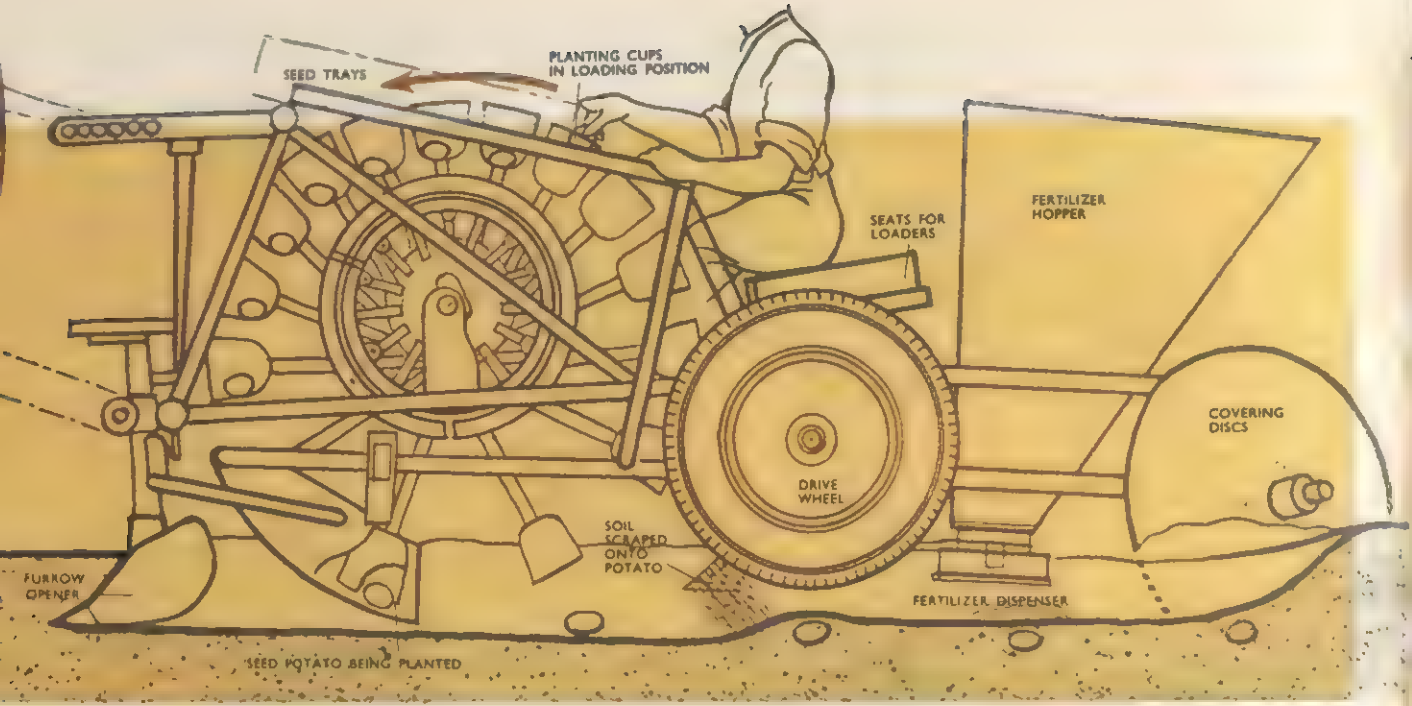
Analysis of plants and plant ash shows that plants consist mainly of carbon, hydrogen, oxygen and nitrogen, small amounts of iron, magnesium, aluminium, calcium, potassium, sodium, silicon, phosphorus, sulphur and chlorine, and very small amounts of boron, molybdenum, manganese, zinc, and copper. These last elements are known as *trace elements*.

Scientists are gradually finding out what roles these various elements have in the life of the plant. For instance, while certain minimum quantities must be present in the soil, too great a quantity may also be harmful, so that the application of artificial dressings to the soil must be carefully balanced.

Farmyard manure, used by itself, will not maintain soil fertility at a level sufficient to keep crop yields constant, and so present-day farmers must also use artificial fertilizers.

The adding of artificial chemical fertilizers was first tried by John Lawes in the 1840's. He found that a beneficial effect was to be had by putting 'superphosphate' (bone-calcium phosphate dissolved in sulphuric acid) onto the soil. After this success other fertilizers were found and used. These included Chile saltpetre (sodium nitrate) and ammonium sulphate. Large supplies of the latter became available as the production of gas from coal increased, as ammonium sulphate is a by-product.

At the present time there are a great number of fertilizers on the market, still including Chile saltpetre, superphosphate and ammonium sulphate. Demand is great and it is a matter of considerable economics to possess supplies of these, or to be able to manufacture them cheaply in large quantities. Synthetic ammonia, made by the catalytic combination of hydrogen and



A method of spreading fertilizer with seeds.

nitrogen, can be produced in vast quantities and is proving a cheaper source of nitrogen than saltpetre.

Phosphate-containing fertilizers can now be made cheaply from basic slag, a by-product of the steel industry. Other fertilizers we have to buy – for example, most of our potassium-containing fertilizers come from Germany, as we have few ready supplies of it at home.

Organic fertilizers are being developed, but because of their relatively high cost they are used mainly in horticulture on a fairly small scale.

Because plants and soils differ widely in their requirements fertilizers are mixed together in different proportions before they are sold. If you look at a bag of fertilizer you will see the amount of nitrogen (N), the amount of phosphate, expressed as P_2O_5 (phosphoric acid), and the amount of potassium, expressed as K_2O (potash), it contains.

For example, ammonium sulphate contains N–20·8 per cent (ammonium, NH_4, contains nitrogen) and sodium nitrate contains N–16 per cent (sodium nitrate $NaNO_3$).

Remember that the initial production and present-day use of fertilizers relied on knowing what the plant required and how its life was related to the soil.

Fertilizers are of two main types, *organic* – animal and plant material, and *inorganic* – either synthetic (e.g. Sulphate of Ammonia) or natural (e.g. Potash, which is used as it is mined). In order to get a balanced dressing compound fertilizers are usually sold. These consist of several single fertilizers mixed together in known quantities. This is necessary because some only supply one substance (Dried Blood – nitrogen; Sulphate of Ammonia – nitrogen; "Rock Phosphate" and Superphosphate – phosphate; Sulphate of Potash – potassium) and others supply two (Bone Meal – nitrogen and phosphate; Nitrate of Potash – nitrogen and potassium).

Fertilizers are available in granular form as well as powder, the former being essential for even distribution.

2. Composting (and manuring)

The art of composting is one that has been known to man for many years. For example, in Japan and China intensive cultivation has been achieved for at least 4,000 years, largely by the intelligent and wide use of compost.

Compost is strictly a mixture of various kinds of animal and vegetable waste material, though nowadays attempts are being made to compost numerous other wastes. Household refuse, for example, minus tins and other metallic material, is pulverised, sifted, wetted and then aerated by stirring. Bacteria are added, to augment the actions of the normal population of micro-organisms, and the harmful substances in the waste are broken down chemically. The digested matter (compost) is dried and bagged. Enriching substances such as phosphate, nitrate and so on may be added prior to bagging.

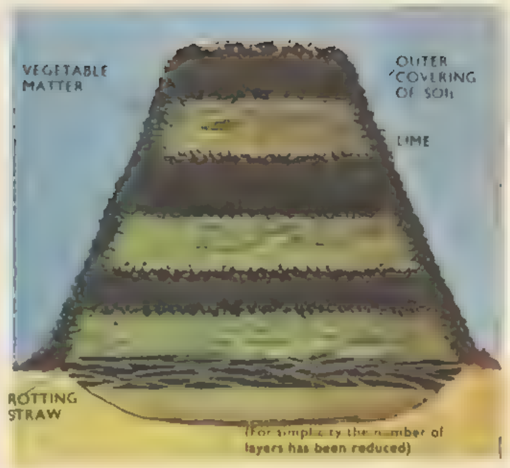
The main aim of composting is to produce *humus*. This consists of the broken-down remains and wastes of animals and plants – the so-called *soil organic matter*. Worms, insects, larger animals and their droppings, dead leaves and branches and myriads of bacteria, fungi, protozoans, and algae all contribute to the humus. It consists of substances in various stages of decay, and contains fluctuating populations of living organisms.

Of great importance in the making of humus are earthworms. They eat their way through the soil, allowing air to enter and turning the soil over. They drag plant material down into their burrows, bringing it into contact with the teeming soil population. The actions of weather and the millions of living soil inhabitants convert the dead and decaying plants and animals into the familiar 'earthy mould' that is mature humus – a material rich in protein and other organic molecules and various kinds of minerals.

The presence of humus promotes the uptake (by the plant) of substances such as sulphate, phosphate, nitrate and iron. It darkens light-coloured soils, and as a result they become warmer through absorbing a greater proportion of the sun's rays. Humus also gives the soil a crumbly texture, binding light, sandy particles together and helping it to retain water, and yet reducing the stickiness of clay, improving its drainage and air supply.

The art of composting is to stimulate the natural production of humus in the soil – achieving the right balance of wastes and soil and providing the conditions that promote their rapid decomposition by micro-organisms.

Composting is a valuable means of changing what would often be an offensive mass of otherwise waste materials into something that will act both as a manure and as a soil improver. Generally it is more efficient to apply well-rotted compost to the soil than to turn raw plant and animal waste directly into the soil.



A section through a compost heap to show the shape and the arrangement of the various layers.

Nowadays compost can be spread rapidly by mechanical means.

Compost contains many substances, including mineral salts, that green plants and soil micro-organisms require in order to make food.

Research has shown clearly that there are considerable differences between a compost heap that is sodden and poorly aerated and one that is moist and has a good air supply. Different micro-organisms thrive in each instance. In the former case the only microbes that grow and reproduce are those that are able to utilise the chemicals in the compost when free oxygen is absent or when it is present in minute quantities.

They are said to be *anaerobic*. *Aerobic* organisms can grow and multiply rapidly only when abundant supplies of air are available. A moist, well-aerated heap satisfies these requirements. Moulds and heat-loving (thermophilic) bacteria thrive in such conditions, fixing nitrogen and producing large quantities of heat so that the temperature of the compost heap rises. In a well-made compost heap temperatures of 150–160°F are produced. At these temperatures disease-causing bacteria and the eggs, larvae and pupae of flies are killed, and so the latter cannot breed. Heat also kills weed seeds. If a compost heap is not well drained and aerated, however, little heat is generated by the anaerobic microbes and so pathogens (disease-causing bacteria) will multiply and flies and other pests are provided with ideal facilities for breeding. Such heaps often release unpleasant smells and they lose their nutrients (particularly nitrogen) very rapidly.

Many wastes may be used to make a compost heap. Those from the house include egg-shells, tea-leaves, carpet sweepings, rags, and dead flowers. Lawn cuttings, bonfire ash, weeds, straw and hay refuse, and animal and bird manures are wastes from farm or garden. Many other wastes may be added too, such as hedge-cuttings, wood-shavings and sawdust, grain husks, various bagged organic manures (e.g. treated sewage), and minerals such as lime. The latter is an important additive which prevents the heap from becoming too acid and also helps to destroy weed seeds.

All waste materials added to the heap should be moist. They should be arranged in layers on top of the foundations, with thin layers of soil containing lime in between. Animal manure helps speed up decay and is valuable next to vegetable remains. As the heap is built up it should be sloped inwards to form a flat ridge. A final covering of peat or moss is needed with an outer layer of soil. This forms a heat-retaining 'skin'.

Compost that rots slowly should be turned two or three times in the first year to mix up the ingredients and to give even rotting. When the compost takes on the appearance of an earthy mould it is ready for use.

Lucerne (*Medicago sativa*) or Alfalfa is characterised by deep roots. It can thus be grown in drier regions than most other legumes. The crowns of the plants throw up many new shoots each year.

3. Ploughing-in leguminous crops

A field of clover is a welcome sight in summer, but the farmer does not sow it just because it looks nice! Clover belongs to the family of plants called the Leguminosae, so called because the fruit is always a pod or legume.

One of the values of leguminous crops lies in the fact that they have a very high nitrogen and protein content. This is due to the action of certain bacteria which live in nodules on the roots. These bacteria, as has been mentioned before, can 'capture' atmospheric nitrogen and make it into nitrates which the plant absorbs and turns into proteins.

Because of this feature legumes such as clover are often used as 'green manure' – that is, the plants are ploughed back straight into the soil and provide there quite an amount of nitrogenous fertilizer.

A plant of red clover (Trifolium pratense) *showing the root nodules and (in circle) one of the types of bacteria that help to fix nitrogen.*

New methods in farming

All agriculture is concerned with turning crops into food, either directly, as in the case of vegetables and cereals (arable farming), or indirectly by first converting the crops into milk, eggs or meat (animal husbandry). New methods for increasing output of food, for most efficiently utilizing the land and its resources, have proceeded in both these aspects of farming.

Animal husbandry

The first development in husbandry was the change from hunting to farming, when man found it more convenient to rear and control his own animals than to prey on wild ones. Today, in an overcrowded society like our own, only an artificial system of farming can possibly meet our needs. It is necessary that every bit of land should produce as much fodder as possible and that the fodder should be converted into foodstuffs as economically as it can be.

Until thirty or forty years ago the mainstay of the stock-farmer was his permanent pasture; to destroy the precious turf of a meadow was looked upon as a crime against the land. Today the vast majority of pasture is ley pasture – that is, land which has been ploughed up and reseeded with fodder crops which may last anything from one to four years. By sowing quick-growing grasses and clovers and by using artificial manures the farmer can produce heavier swards of greater food value; what is more, he can plan ahead and grow fodder crops which are ready for grazing in succession as they are needed, instead of all at the same time.

The development of new strains has also been of great significance, especially in extending the growing season. The 'late-bite' of autumn grass and the spring-flush of new grass are steadily creeping round the calendar towards a winter rendezvous. This is especially important to milk producers who rely upon fresh grass to keep their output steady. New combinations like clover and rye grass or lucerne and rye grass help to grow good crops on what was formerly poor land.

The years since the war have also seen great advances in the production of winter fodder. The techniques of haymaking, for example, have been revolutionized. The *baler* has made carting and stacking the crop a much easier business than in older days when it had to be handled loose. Machinery firms have produced a range of new equipment to hasten the 'making' of hay (i.e. drying out the cut grass). *Swath-turners* which turn over the drying hay are a comparatively old invention. They removed the need for gangs of workers equipped with wooden rakes. Newer machines include the 'crimper', which breaks or crushes the stems of grass, thus helping the moisture to evaporate, and various tools designed to 'fluff up' the swathies (the bundles of hay) and allow air to circulate.

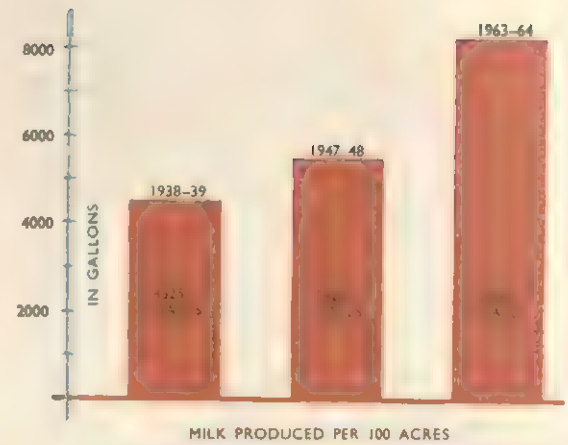
Silage has been another modern development. Instead of drying grass out as in haymaking, it is taken while still fresh and mixed with molasses in layers in a silo or pit; the resulting 'pickle', though powerfully smelling, is extremely palatable to cows. The popularity of silage has given birth to one of the newest of agricultural machines – the forage harvester. Towed by a tractor which also provides its power, the forage harvester uses chain-like flails to cut and lacerate grass; it then blows the grass through a spout into a high-sided trailer. This machine has taken much of the labour out of silage-making.

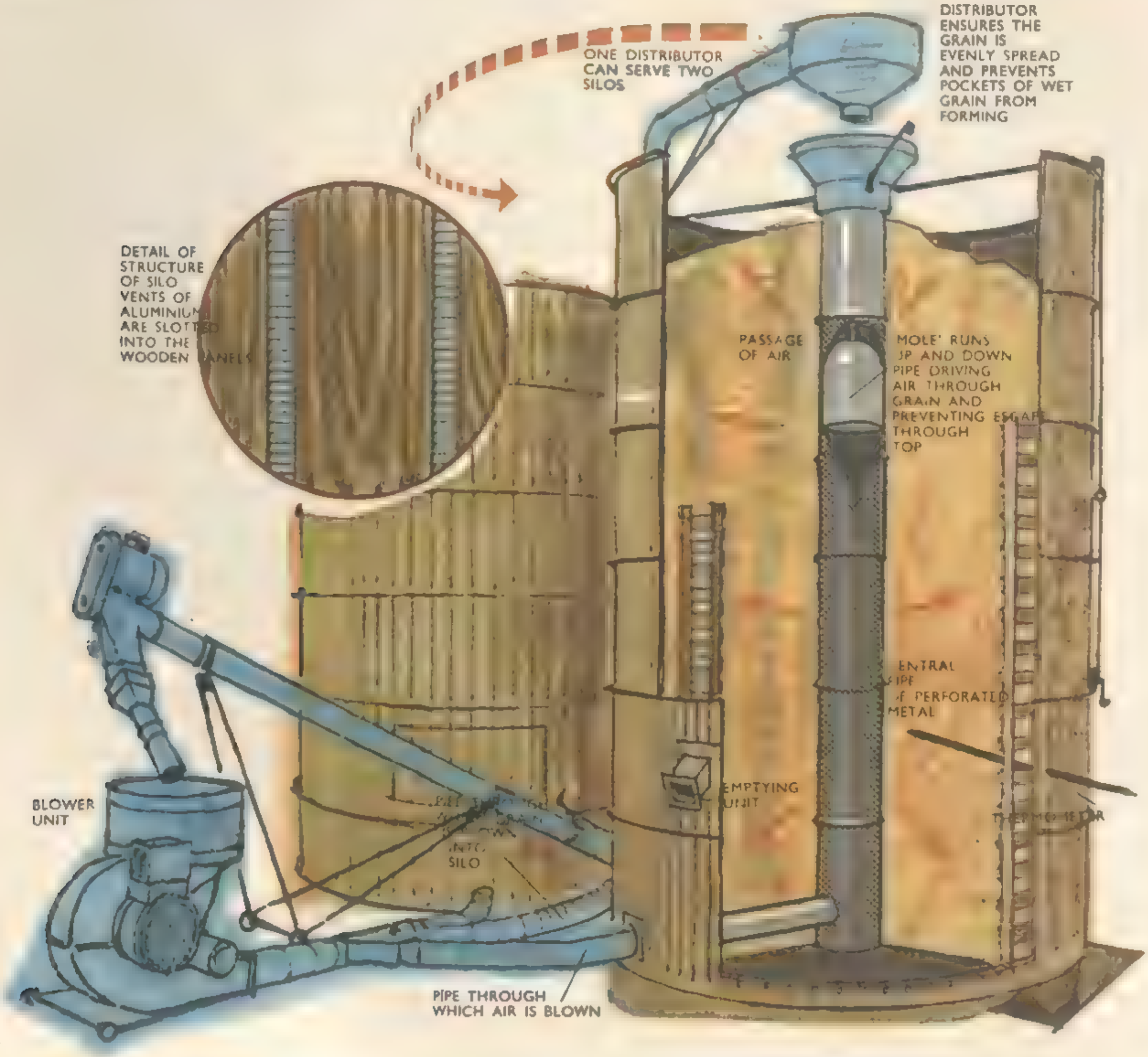
With rich ley-crops, often growing 6 inches high, the ordinary process of free-grazing by cattle tends to be wasteful, much of the crop being trampled or fouled by the animals. One solution is strip grazing, which is a development of the 'folding' system used when cattle or sheep are grazing winter fodder such as kale. Each day the animals are allowed a fresh piece of grazing. If this is of the right size it will be eaten thoroughly and the remainder of the crop remains unspoilt. Usually a portable electrified fence is used to divide up the plots.

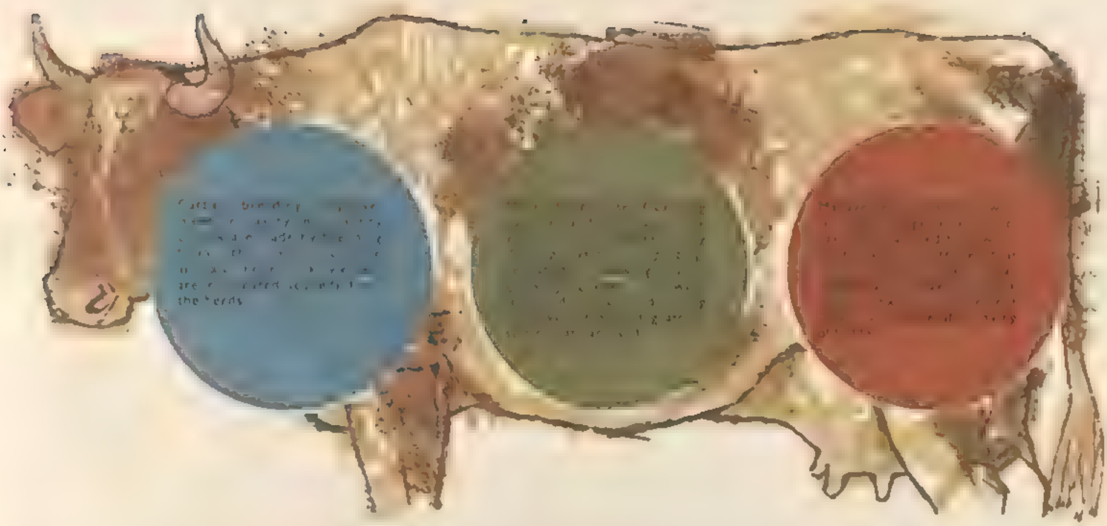
A further development, still in the experimental stage, is 'zero-grazing'. This system, started in the United States, goes even farther and takes green fodder to the animals instead of vice versa. By using a forage harvester the crop can be gathered as it is needed, and without waste. Moreover, the animals can be given known rations which will result in the most economic food-conversion rates. This system can be used for cattle, for either milking or beef herds.

In the case of beef-production much effort has gone into experiments to discover ways in which beef may be produced more quickly and cheaply. The traditional method of beef production takes two years and often involves two farmers – the rearer and the fattener; the yearling cattle change hands as 'stores'. The new

The production of milk in Britain has continually risen as shown by the illustration.







A number of factors have played a part in the increase, from animal and plant breeding to careful measurement of food supplies allocated.

methods speed up the process and intensify it. Instead of being reared and fattened on a basic diet of grass and hay the animals are taken as calves and fed concentrated rations based on barley – hence the term 'barley-beef' – with the addition of manufactured 'nuts' and just enough roughage (i.e. hay etc.) to keep the digestion healthy. This method of intensive rearing produces a tender beef carcase within a year of birth – though there is criticism that it makes the meat lean and tasteless. At present, the barley-beef system is used mainly in rearing dual-purpose animals – that is, calves from dairy herds, particularly Fresians, rather than the pure beef cattle which produce the top-class meat.

The 'factory' system of rearing calves for veal is based on a similar intensive system which aims at converting as much vegetable food as possible into meat. These methods, which rely on careful measurements and mixture of rations, were pioneered in the pig industry, where the animals are traditionally kept confined and fed on meal and concentrates rather than being allowed to forage for their food. While intensive methods of husbandry may become increasingly important in producing beef, veal and pig-meat, it is unlikely that sheep will be affected; they are, in any case, more efficient grazers than cattle and are often kept on marginal land, i.e. hill-pasture and poor soil, which does not lend itself to cultivation.

Section through a grain-drying silo. The increased quantity of grain produced by combine harvesting, is dried and stored here. The silo is made of wood which absorbs moisture and prevents condensation.

Arable farming

One of the chief factors which has made possible the increase in cereal production has been the invention of the combine harvester. Previous methods of harvesting – cutting the corn with a reaper and binder, drying the corn in the stook, stacking the crop and threshing it later – made large labour forces necessary and placed too much reliance on an unreliable climate. At a stroke, the combine reduced harvesting to a single operation, only needing a few men.

Continual improvements of the combine harvester made necessary revolution in methods of handling the harvested grain. Because the corn is threshed immediately, it does not dry out as thoroughly as it did in the stook. Grain can only be stored safely if it contains less than 16 per cent moisture; above this figure fermentation will set in, raise the temperature and eventually rot the grain. Grain drying became a necessity to cope with the larger crops which combines could handle. At the same time bulk handling of grain became increasingly important. If sacks are eliminated and the crop is mechanically handled in bulk, the saving in labour is immense. A whole new range of equipment came into use: hydraulically tipping trailers to cart the grain, cleaners to remove dirt and grass which hinder drying, augers and elevators for moving the grain, and enormous silos for storing it. The latest grain dryers combine the function of drying and bulk storage; the grain is placed in large silos in which air can be blown

It used to take 12 men 6 to 7 weeks to harvest 100 acres of corn and another 2 to 3 weeks to thresh it.

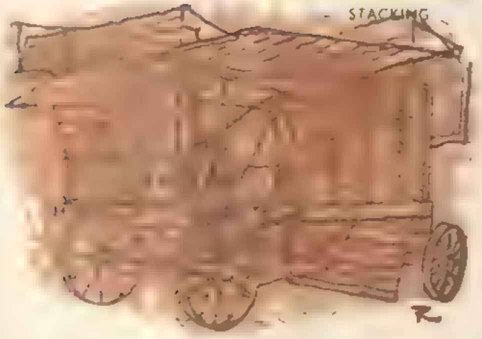
Now it takes 2 men using a combine harvester 2 weeks to harvest the same quantity of crop and have the dried grain safely in store.

through it, thus removing excess moisture and making it safe for storage, 50 or 60 tons to a silo.

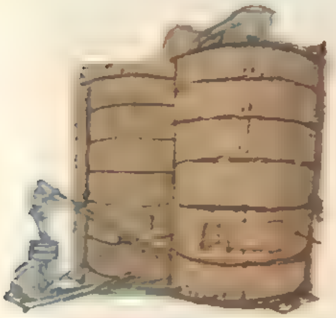
A promising new development in this field is so-called 'wet-storage'. Grain is placed in sealed silos while still damp, and the initial stage of fermentation produces carbon dioxide which replaces oxygen in the spaces between individual grains and thus prevents further deterioration. This method will obviously have important applications, especially if current experiments are successful in proving that it has no adverse effect on germination in seed corn.

The second major factor has been the development of artificial fertilizers, which has largely put an end to the rotational system of farming in corn-growing areas. For 200 years arable farming has been dominated by the need to intersperse grain crops with greens and root crops in order to rest the land and restore nitrogen and other elements absorbed by the growing corn. The

STACKING



THRESHING



DRYING AND STORING

only alternative was very heavy use of animal manure, which was not practical on a very large scale. The development of artificial fertilizers put an end to this. By applying them to arable land it is now possible to grow even better cereal crops year after year without exhausting the land. At the same time the careful use of chemical weed-killers has helped to keep crops 'clean'.

It is certain that in future arable farming will rely more and more on science – to analyse and repair deficiencies in the soil; to provide artificial fertilizers, chemical pesticides and herbicides; to breed more prolific and disease-resistant strains of the main cereal crops. As well as this, the engineers will produce better machines to tackle bigger jobs more quickly, so cutting down the labour required and making the farmer more and more independent of the climate.

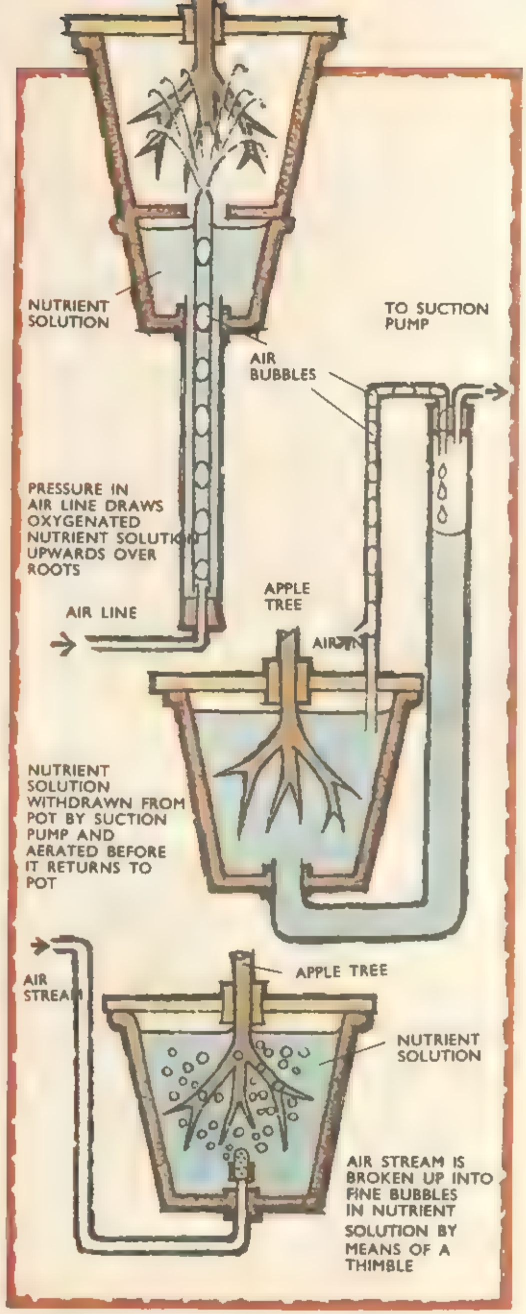
Crops without soil

More than 250 years ago the first recorded attempt was made to grow plants solely in a liquid medium. In 1804 a Swiss, de Saussure, carried out more controlled experiments, culturing plants in dilute solutions of various salts. Amongst other things, he showed that a plant is able to absorb the salts it requires from very dilute solutions. From these early beginnings the science of *hydroponics* has emerged Hydroponics is the growing of plants in solutions of pure chemicals.

In the first place, hydroponic methods were confined solely to the laboratory. The early plant physiologists used water-culture methods to determine the way in which plants feed and the salts that they require. Today, water culture methods are still an important research tool, but they also have commercial application. Some tomatoes and cucumbers, for example, are grown by hydroponic methods. Moreover, purely hydroponic techniques have been superseded by others in which the plants are provided with a medium to root in – sand, gravel and vermiculite are commonly used. The rooting material may be supplied with solid fertilizer which is washed in with water, or with liquid fertilizer containing the necessary salts in the correct proportion. A more advanced method – the *sub-irrigation system* – involves flooding the rooting material (*aggregate*) by pumping in a nutrient liquid at pre-set intervals. Surplus solution drains back very slowly, by gravity, into the large storage tanks and is then available for recirculation. Disadvantages of this method are mainly that the strength of the solution decreases gradually with each application, and, more serious, the proportions of the salts dissolved in it may change. Analysis of this is tricky and requires careful and skilful estimation, for many of the required nutrients are present only in minute quantities. Such elements as molybdenum, manganese, copper, boron and zinc are needed in amounts less than one part per million in solution. Some substances must be added from time to time to maintain the correct proportions of mineral salts.

However, soilless cultivation has several advantages over normal horticultural methods (though the reverse is also true). The plants can be fed so much more intensively that more can be cultivated in a given area

Three methods of supplying aerated nutrient solution to apple trees.



and thus greater yields are obtained than with plants grown in soil in the ordinary way. The feeding can be related to an aggregate whose physical properties are known and which remain relatively constant.

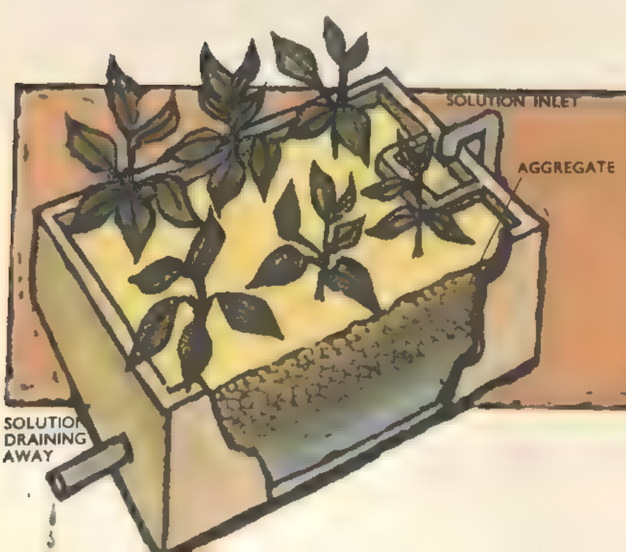
The soil is an ever-changing environment responding both to mechanical and physical factors, such as rainfall, temperature, the drying effects of sun and wind, and the living population. Its organic content (i.e. decaying animal and plant matter) is continually changing, as it is broken down by bacterial and other activity and as the growing plants use up nutrients. The results of applying nutrients and other substances are less predictable, therefore, and soil borne pests are less easily controlled.

Where overhead watering is employed it is best to use an aggregate that dries out slowly. Clean sand of medium grain size is most suitable, whereas for sub-irrigation techniques a coarser aggregate, such as gravel, is needed.

The composition of the nutrient solution and how often it is applied will vary with the requirements of different plants and also with the season and local weather conditions. A high phosphate level encourages the early ripening of many crops. Tomatoes are responsive at different times of the year to varying proportions of the three major plant nutrients – potassium, nitrogen, phophorus – and so the dosage is varied to produce the maximum yield.

This is just one example of how the knowledge of a plant and how it relies on its environment may be used to help Man supply himself with food.

A tank set up for soilless culture.



GENERAL PURPOSE NUTRIENT SOLUTION

SODIUM NITRATE	28 OUNCES
POTASSIUM SULPHATE	4 OUNCES
SUPERPHOSPHATE OF LIME	14½ OUNCES
MAGNESIUM SULPHATE	9 OUNCES

all dissolved in 100 gallons of water plus another solution containing ½ oz Boric acid, ¼ oz Manganese sulphate, 3 oz Iron sulphate dissolved in 1 pint of water and added to main solution – three tablespoonfuls per 100 gallons

Additional Questions

1. In an effort to find out if Dog Whelks have a sense of direction and where they prefer to live on a shore a large sample of four hundred was collected. This sample was then divided into four groups of one hundred—A, B, C, and D.
All the whelks in A and B were painted red, and all those in C and D were painted green.
Four almost identical pieces of gently sloping shore were chosen; in each case the shore was rocky with some cracks and pools, and sea birds were plentiful.
Group A was taken to the first piece of shore and was spread out along the High Tide mark.
Group B was taken to the second piece of shore and was spread out near the Low Tide level.
Group C was taken to the third piece of shore and was spread out along the High Tide mark.
Group D was taken to the fourth piece of shore and was spread out near the Low Tide level.
They were all left for three days, and then each piece of shore was examined to see what had happened to the whelks. The results of the examination were as follows:

GROUP	FOUND DEAD	FOUND ALIVE	MOVED UP SHORE	MOVED DOWN SHORE	FOUND IN CRACKS	STAYED STILL
A	37	22	1	6	15	0
B	19	41	22	9	0	10
C	16	40	3	11	26	0
D	2	51	25	11	0	15

In each case the dead ones were widely scattered, had their shells broken and were eaten inside.
That is an account of an experiment, now see what conclusions you can reach by answering the following questions:
What was the percentage recovery from each of the groups? e.g. Total number at start = a, number recovered alive = b, number recovered dead = c.

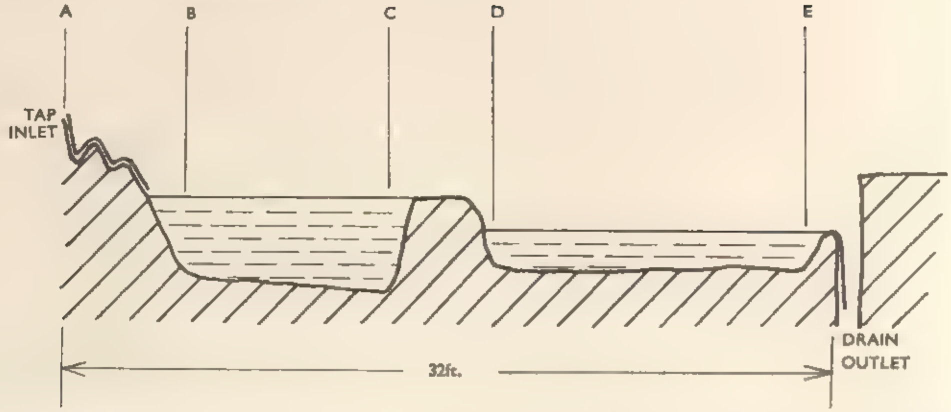
$$\text{Percentage recovery} = \frac{(b+c)}{a} \times 100$$

What is the average percentage recovery from all the groups?
What might have happened to the others?
What percentage of each find was dead?

$$\text{e.g. Percentage dead} = \frac{c}{(b+c)} \times 100$$

Is there any difference in the percentage dead at High Tide mark and at Low Tide mark? Can you explain this?
Is there any difference in the percentage dead of red ones and of green ones? Can you explain this?
Quite a number of those found alive at the High Tide mark were found in cracks and crevices. Why?
Why also were none found in cracks and crevices at Low Tide mark?
Finally, can you suggest at what level on the shore the whelks prefer to live: at High Tide level, at Low Tide level, at Mean Sea level, between the High Tide and Mean Sea levels, or between Low Tide and Mean Sea level?
If you cannot answer this last question what improvements would you make in the experiment to enable you to do so?

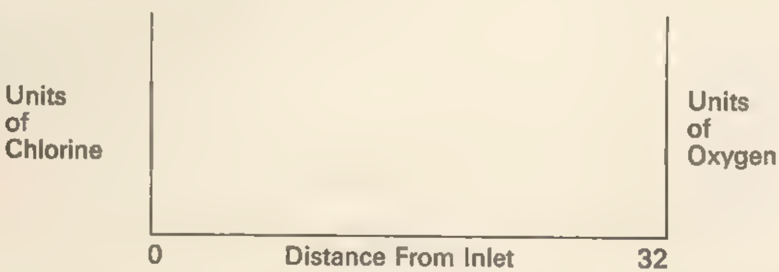
2. Here is a sectional diagram of an artificial pond:



On looking at the pond it could be seen that some plants were growing in the deep end of the pond but that most were growing in the shallow end.
A lot of insects lived in the shallow end, but some lived in the deep end and these were the sort which used oxygen from bubbles drawn from the surface. Frogs and newts lived in the shallow end.
The water in the pond came from a drinking water tap at point A.
Can you suggest reasons to explain the distribution of animals and plants in the pond?
Some samples of water were taken from the pond in five places and were analysed for two dissolved gases, oxygen and chlorine. The results are as follows:

	A	B	C	D	E
UNITS OF OXYGEN	0.75	2.25	3.25	4.5	5.0
UNITS OF CHLORINE	8.5	6.0	3.25	1.75	0.75

Plot these results on axes as follows:



Now can you add any further reasons to your explanation of the distribution of life in the pond?
Why do you think the following features were built into the pond?
The series of small waterfalls at A.
The weir between C and D.
A deep end and a shallow end.
Do you think that it might be safe to drink water from *this* pond? If so, from which point, and why?
If you wanted to keep tadpoles indoors in an aquarium and wanted to fill it with pond water from this pond, where would you fill it from?
Supposing you had collected some pond organisms from any pond and wanted to keep them in an aquarium for observation but only had tap water with which to fill it. What might you do with the tap water first in order to make it safe for the organisms?

3. If a wood is examined at intervals throughout the year it becomes apparent that a more or less regular timetable exists by which things happen. For example, with slight variations according to the weather, deciduous trees always lose their leaves in Autumn and develop new ones in Spring. That is a most obvious example, and closer examination of woodlands shows a much finer sequence of events.
Consider the life of flowering ground plants in a wood: they carry their flowers and leaves for a relatively short period of time, but nearly always they come into leaf and flower at the same time of year. What factors control such events—is it the weather alone or are other factors involved?
Let us take as examples the following flowers: Wood Anemone, Primrose, Celandine, Dog's Mercury, Early Purple Orchid, Bluebell, Violet, Ground Ivy, Honeysuckle, Butterfly Orchid.
Most of these are fairly common and can easily be found, with the possible exception of orchids. Here is a table showing two features of these flowers.

FLOWER	*FLOWERING PERIOD*	*POLLINATING AGENT*
WOOD ANEMONE	MARCH-MAY	INSECT
PRIMROSE	FEB.–MAY	INSECT
CELANDINE	MARCH–MAY	INSECT
DOG'S MERCURY	FEB.–APRIL	WIND
EARLY PURPLE ORCHID	APRIL–MAY	INSECT
BLUEBELL	APRIL–JUNE	INSECT
VIOLET	MARCH–MAY	PROBABLY INSECT
GROUND IVY	APRIL–JUNE	INSECT
HONEYSUCKLE	JUNE–SEPT.	INSECT
BUTTERFLY ORCHID	MAY–JULY	INSECT

Look at the flowering periods in the table and note how early in the year most of them start.
Why does a plant produce a flower?
Pollination is an essential part of the process with which flowers are concerned. Two main pollinating agents are employed, wind and insects, and these are given in the table for each flower.
What changes would you notice if you went into a wood in January, and looked upwards, then returned in May and looked upwards?
How would these changes affect the plants at ground level?
At what times of the year and in what conditions would the wind be most felt at ground level in a wood?
Where does one normally find most insects—in the warm sun or in the cooler shade?
In which conditions does a plant normally photosynthesise best—in light or in shade?
Tree flowers are usually pollinated by wind. Would it be more suitable for their flowers to develop before their leaves or vice versa?
One of the plants in the table has quite a different flowering period from the others, it is the Honeysuckle which flowers much later than most. Has this plant any special feature which might help it to exist at this later period?
As well as the Honeysuckle the Butterfly Orchid is also quite a late flowerer. Both of these plants have light coloured flowers (the Orchid is white) and also they both have strong scents which are particularly evident in the evening.
Could these adaptions cause these plants to be suitable for pollination by any particular group of insects?

From your answers to these questions can you erect a hypothesis as to what factors seem to control the timing of the life cycle of these woodland flowers?

4. The counting of organisms is a job which has frequently to be done by people studying ecology, and when large numbers of small organisms have to be counted it is far from easy. Let us consider two methods.
Suppose you have been asked to count the number of frogs in a large pond at spawning time, how could you do it? It would be most unlikely that you could catch all the frogs at once to count them, and it would be equally unlikely that you could count all the frogs in the water while they were swimming around, even if you could see them all! But if the pond was visited and, say, forty frogs were caught and marked with spots of bright paint, then released into the water again, the task becomes quite easy. If the pond is revisited and a sample of twenty frogs is caught, ten of which are marked, then the total population can be worked out as follows:
Forty marked frogs were released into the population, and out of a sample of twenty caught ten were marked.

By simple proportions 10:20 as 40:P, (P=Total Population)

or $\frac{10}{20}=\frac{40}{P}$

$10P=20\times40$

$10P=800$

$P=\frac{800}{10}$

$P=80$

Following are some results taken when such a count was being made. Fifty frogs were marked and released and left for a day. The pond was then revisited for the next five successive days.

DAY	SAMPLE NUMBER	NUMBER MARKED
1	40	7
2	60	13
3	55	11
4	70	12
5	45	8

What is the total population of the pond?
Why were readings taken over five separate days?
What action by the frogs could cause such an estimate of the population to be invalid?

The counting of plants is quite another problem. At least they do not move around when they are being counted, but they are usually present in such large numbers as to make entire counting almost impossible. Here again a method of sampling must be used and an estimate of the whole number made.
Let us suppose that again you have been asked to do the seemingly impossible task of counting the number of Plantain plants on the school games field. They are difficult to see and are scattered all over the field in a haphazard fashion.
Here is one way of attempting it:
The field is 200 yards square. Choose three lines parallel to one another, one 50 yds from one side of the field, one 100yds from the side, and the other 150 yds from the side. These lines are called transects: transect A, transect B and transect C. At equal intervals along these transects known areas of ground must be sampled and counted for Plantains. The known areas of ground are kept constant by using a quadrat. (A simple quadrat can be made by tying four yards of string in a loop, and by tying nails to the string at yard intervals. When the nails are pushed into the ground in the form of a square the string will enclose one square yard of ground.)
This quadrat is put onto the ground on the line of transect A at one end of the field and the number of Plantains within the area of the quadrat is counted and recorded. The quadrat is then moved 20 yds along the transect and another count is made. This is repeated until transect A is completed, then transect B is done, then finally transect C.
The results from such a count might look as follows:

QUADRAT NO.	TRANSECT A.	TRANSECT B	TRANSECT C
1	4	4	4
2	4	4	4
3	0	0	0
4	4	1	2
5	5	1	4
6	3	1	7
7	4	3	3
8	0	4	2
9	0	6	1
10	4	4	3
11	4	4	4

How many plantains do you think there are on the whole field?
What is the average density of Plantains per square yard of field?
Part of Transect A runs along the goal line of a football pitch.
Part of Transect B runs through the cricket square.
A well used path runs along one side of the cricket square.
By using the results in the table and these three facts draw a sketch of the field.

Index